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Station

Needs Assessment for Water-Level Gauging Along the Texas Coast for the U.S. Army Engineer District, Galveston

by Nicholas C. Kraus, WES

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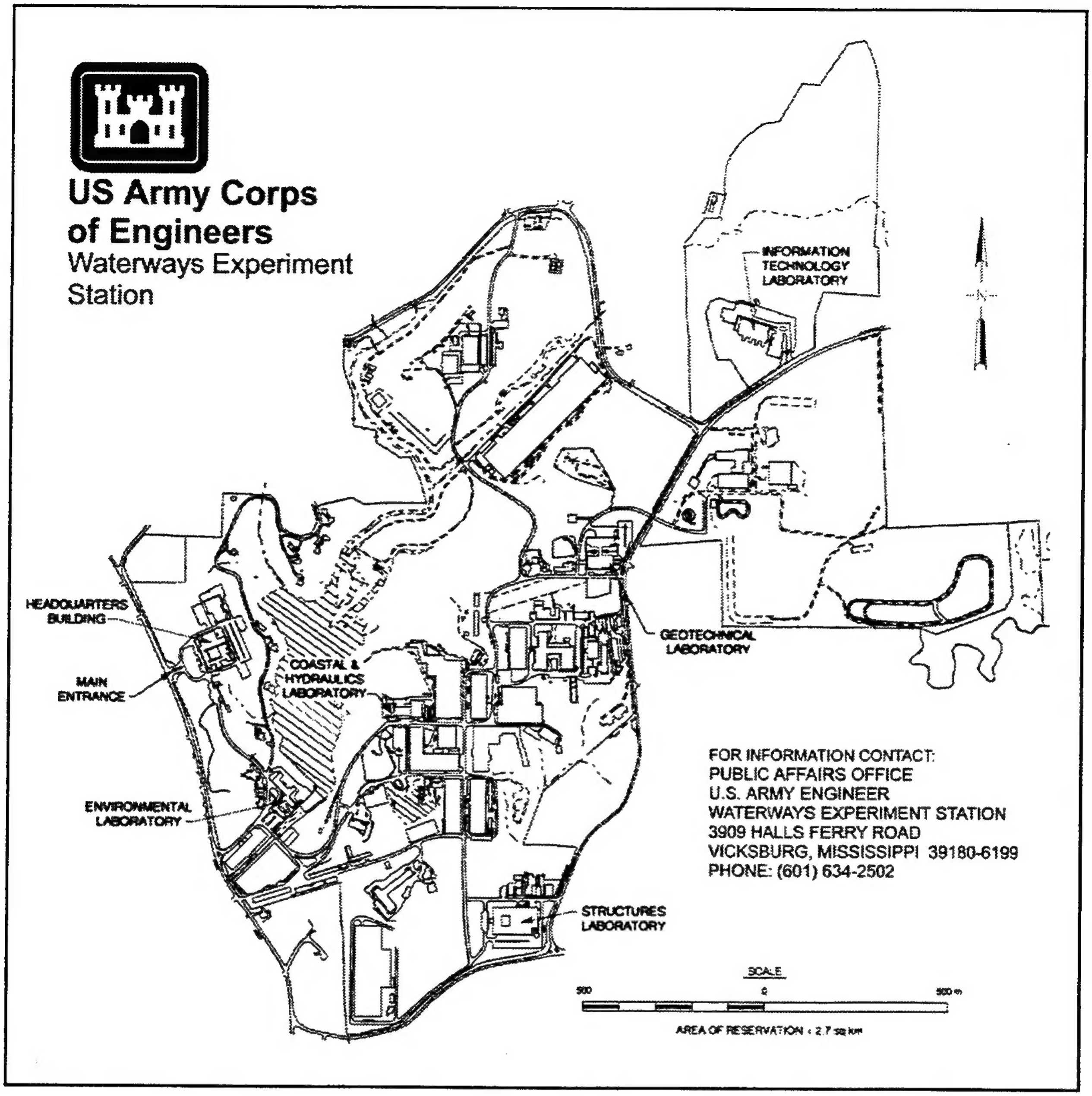

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Preface

The needs assessment for water-level measurement and associated information described in this report was conducted for the U.S. Army Engineer District, Galveston (CESWG). Work was performed under Modification/Amendment No. P00003 of Contract No. DACW64-95-C-0018 with the Conrad Blucher Institute (CBI) for Surveying and Science, Texas A&M University-Corpus Christi, in support of the Texas Coastal Ocean Observation Network (TCOON). Notice of authorization to proceed with work under the amendment was received on 29 April 1996. An interim draft of this report was provided to CESWG on 30 September 1996.

The assessment was performed by Dr. Nicholas C. Kraus, formerly Director of the Division of Coastal and Estuarine Processes, CBI, and presently Research Scientist, Coastal and Hydraulics Laboratory, CHL), U.S. Army Engineer Waterways Experiment Station (WES); Mr. Carroll I. Thurlow, consultant to TCOON and formerly Chief of the Tides and Water-Level Program for the National Ocean Service (NOS), National Oceanic and Atmospheric Administration; and former CBI staff members; Mr. Daniel J. Heilman and Ms. Anne-Lise Lindquist, Research Scientists, and Mr. Mark W. Earle, Communications Specialist. Technical points of contact at CESWG were Mr. John Rozsypol, Ms. June Keller, Mr. Ron Meyers, and Mr. Tom Hunt. The field reconnaissance benefited from the assistance of numerous staff members of Area Offices and Field Offices of the Galveston District: Mr. Randy Batiste, Port Arthur Field Office; Mr. Isidro Garcia, Brownsville Field Office; Mr. Ramon Sierra, Southern Area Office, Corpus Christi; Mr. David Torrez, Bay City Field Office; and Mr. Rick Tryals, Northern Area Office, Galveston. General assistance to the study was also provided by Galveston District staff members from the

Southern Area Office, Corpus Christi: Mr. Carl Anderson, Area Engineer; Mr. Domingo Galindo, Project Engineer; and Mr. Elijio Garza, Civil Engineer.

This study received assistance from TCOON staff at CBI, in particular, by former TCOON Project Manager Mr. T. Zachariah Jeffries. The cooperation of NOS staff in providing water-level data is appreciated.

At the time of publication of this report, Dr. James R. Houston served as Director of the CHL; Assistant Directors were Messrs. Richard A. Sager and Charles C. Calhoun, Jr. Director of WES was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.03048	meters
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.609347	kilometers

1 Introduction

This report contains a reconnaissance assessment of needs for water-level information by the U.S. Army Engineer District, Galveston (CESWG). The CESWG conducts navigation channel maintenance and operations along the Texas coast from the Sabine River on the north to the Brownsville Ship Channel on the south (Figure 1). The Texas coast is approximately 350 miles[1] long and contains more than 1,000 miles of deep- and shallow-draft navigation channels running through bays, estuaries, lagoons, and rivers, as well as eight maintained channels running to the Gulf of Mexico through inlets. The CESWG has identified a general need to have both real-time and recorded data on water level for conducting its navigation channel maintenance and operation, coastal engineering, and environmental regulatory functions in an economical and accurate way. This report identifies general and some specific needs for water-level information, and it gives a recommendation for obtaining such information.

Background for the Needs Assessment

The CESWG maintains and operates Federally authorized channels and waterways along the coast of Texas, which include ship channels and the Gulf Intracoastal Waterway (GIWW). In support of its navigation mission, CESWG dredges more than 40 million cu yd of sediment annually. Both Government surveyors and the CESWG's dredging and other contractors perform hydrographic surveys in support of these dredging operations. Such activities associated with navigation channel

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page x.

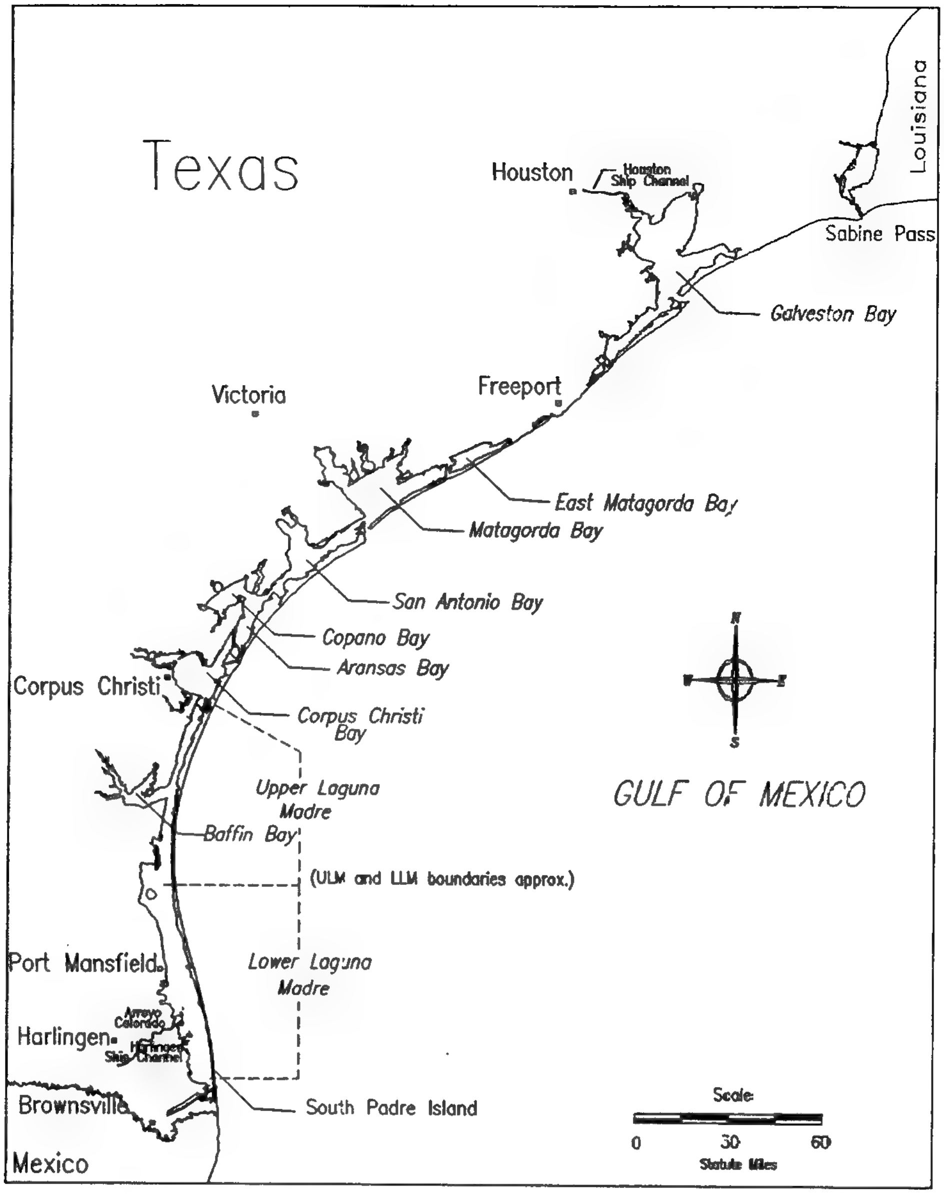

Figure 1. Study site, the Texas coast

maintenance and operation require knowledge of water level prior to, during, and after dredging. The CESWG also conducts coastal engineering works and environmental regulatory functions that involve water-level data. In conducting these activities, information in real time (during the activity) is often needed, whereas in some situations convenient access to recently recorded measurements is sufficient.

In a more general context, the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce and U.S. Army Corps of Engineer (USACE) Districts nationwide are converting to mean lower low water (mllw) as the chart datum for navigational tidal waters of the United States. The NOS is revising charts for the east and Gulf coasts with mllw as chart datum, a several-year process. Tidal datums such as mllw are calculated and published by NOS, and, by mandate of the Congress of the United States, the USACE must reference this NOS chart datum. The Districts are following guidance issued by Headquarters, USACE, in Engineer Technical Letter (ETL) 1110-2-349 (USACE 1993). Also, by ETL 1110-1-152 (USACE 1994), Districts are required to implement the North American Vertical Datum of 1988 (NAVD 88) as a replacement for the National Geodetic Vertical Datum of 1929 (NGVD 29).

The NGVD 29, a standard geodetic reference for elevations, is sometimes confused with or referred to synonymously as mean sea level (msl). The datum msl is defined by NOS as the average of the hourly values of water-level readings of a specific 19-year tidal epoch called the National Tidal Datum Epoch (NTDE), presently 1960 to 1978. However, because there are many variables controlling water level, and because a geodetic datum represents a best-fit surface over a broad area and not to a specific area, NGVD 29 is not, in general, equal to msl. The geodetic datum can deviate from msl by 1 ft or more, depending on location. Thus, NGVD 29 and NAVD 88 are not equal to msl, do not bear a consistent relation to msl along a coast, and are fixed, whereas the elevation of msl typically changes slowly with time.

For several decades, CESWG has recognized that standard low-water datums such as mean low water (mlw) and mllw that are defined in terms of the daily phase of the tide as computed by NOS are not adequate as a navigation datum within the waterways along the Texas coast. This recognition owes to four observations:

a. In the shallow inland coastal waters of Texas, the astronomical tidal signal is very weak, and the seasonal change in water elevation within waterways typically exceeds the range in daily tidal elevation for long periods of time (as long as months).

b. Persistent strong winds that blow daily or move through an area as a weather front have a much greater influence on the change in the water level on the shallow inland coastal waters of Texas, producing either water setup or setdown, depending on location in a water body.

c. Storm surges and water-level changes accompanying differences in air pressure can greatly change water level in shallow basins.

d. Occasional strong river discharges, such as from the Brazos and Colorado Rivers, will temporarily alter the water level more than the astronomic forces.

All four of these phenomena are not directly related to the astronomical or deterministic tide and tidal datums as presently defined by NOS.

In addition, recent densification of tide stations on the Texas coast and inspection of the resultant data have shown that, for much of the GIWW and associated channels distant from inlets, an mllw tidal datum cannot be computed following NOS standards and procedures. The mllw datum is obscure because the meteorologically induced water motions that mask the daily range of astronomic highs and lows is too small. An NOS technical report (Gill, Hubbard, and Dingle 1995) documents the nontidal character of portions of the Laguna Madre. This finding applies to much of the GIWW and associated coastal inland channels. A navigation datum must be developed for such areas as well. The establishment of a fixed low-water datum, such as is used in the Great Lakes and on the Mississippi River for navigational purposes, is the practical solution. Such a datum should be low enough that the water level will seldom, if ever, fall below it. This datum can be readily implemented by specifying the proper design channel depth in terms of the NOS chart datum for the project water body.

In light of such observations, in the 1950s the CESWG established a navigation datum which it called "mean low tide" (mlt) and defined it in terms of a fixed vertical reference, namely, NGVD 29. For example, in the Corpus Christi Bay area, mlt is 1 ft below NGVD. Accuracy achievable with modern instrumentation for measuring water level, as well as the requirement of reference to chart datum, bring the need to relate mlt

to mllw and, preferably, to an as-yet-to-be defined navigation low-water datum for portions of the inland coastal waters of Texas. A rational navigation datum for the Texas coast must be developed and implemented that accounts for the extended periods of time during which water level along the Texas coast lies significantly below mllw.

According to Engineer Manual (EM) 1110-2-1003 (USACE 1991), page 7-1, "when elevations are referred to a tidal reference plane in coastal waters of the United States, mean lower low water (mllw) shall be used as the vertical datum." The manual further states "In coastal areas, every attempt should be made to assure that USACE datums are the same as, or have a direct relationship to (underlining added by present authors), the NOS chart datums. This is essential to ensure consistency for mariners and others using Federal map and chart products.... In making a determination as to the correct datum, Congressional intent (authorization documents) should be considered." The EM also states "If the tidal datum that is used is different from mllw, a diagram should be included on the drawings to indicate the relationship between the project datum (underlining added by present authors) and mllw. The relationship to NGVD 29 should also be shown." Presumably, based on more recent guidance in ETL 1110-1-152 (USACE 1994), the relationship to NAVD 88 should now be shown.

It is clear that guidance provided by USACE technical documents holds provision for definition of project navigation datums, where warranted. If it is not feasible to determine mllw or if it is technically unsound to employ mllw as a navigation datum, then USACE Districts have the authority to develop an appropriate navigation datum. This project datum must be related to mllw or NOS chart datum, if available, for consistency between Federal agencies and in publishing Federal maps and charts.

Since implementation of NGVD 29, the Texas coast has undergone substantial geomorphic change under the influence of natural and human forces that have altered both the relative location of the water level with respect to land and the range of water-level variation. Along the Texas coast, since the beginning of water-level gauging by NOS and its predecessor organizations (Coast Survey, Coast and Geodetic Survey) in

the early1880s, sea level along the Texas and Louisiana coasts has been rising, relative to the land, in great part due to subsidence (Swanson and Thurlow 1973). The rate of relative sea-level rise varies along the Texas coast, but has been measured to be on the order of several millimeters per year (Swanson and Thurlow 1973; Lyles, Hickman, and Debaugh 1988), depending upon location. Relative changes in land-water elevation will directly alter water-level datums at the site of inland-water and coastal operational activities of CESWG, and these changes must be tracked through water-level gauging to fixed benchmarks on land. The National Research Council (1987) has published a monograph discussing the engineering implications of sea-level rise.

Determination of the relation of mlt or of another navigation datum to extreme annual low water level, as well as to mllw as required, will enable CESWG to assure the proper navigable depth, while satisfying Federal-wide and USACE policy. The complex water-level variations present on the Texas coast and along its inland coastal waters necessitate measurement of local water level and collection of long-term time series of measurements. Operational requirements in support of dredging activities call for real-time reporting of the data in many situations.

Cost-Sharing Partners and the Needs Assessment

The State of Texas, through sponsorship by the Texas General Land Office (TGLO) and the Texas Water Development Board (TWDB), has deployed and operates a system of tide gauges called the Texas Coastal Ocean Observation Network (TCOON) (Michaud, Thurlow, and Jeffress 1995). TCOON is maintained to national standards and procedures established and promulgated by the NOS. TCOON complements eight NOS gauges presently operating on the Texas coast. As of September 1996, the TCOON consisted of some 40 gauges, most of which were located in inland coastal waters, with three gauges located offshore near the fairway of the Galveston Ship Channel and sponsored by CESWG. The main purpose of the TCOON has been to provide water-level information to the TGLO for marine boundary determination (boundary between state-owned land and private land) and to the TWDB for its estuary and bay circulation and salinity studies.

The TGLO has proposed that the CESWG become a cost-sharing partner of the TCOON, through which the needs of the District for water-level information can be met. The cost-sharing partnership would support the backbone of primary stations (long-term observations) and subordinate stations (short-term observations – on the order of 3 months to 3 years) upon which the programs of all agencies would depend. The partnership must also consider specific gauges and special requirements identified by CESWG as necessary to conduct its missions.

Water-level measurement needs of the CESWG in support of its navigation channel maintenance, coastal engineering, and regulatory functions will not always coincide with those of the state agencies of Texas in their marine boundary definition and environmental modeling activities. On the other hand, all potential users of water-level information will require a certain backbone of primary gauges and infrastructure of personnel and equipment to support their needs. It is appropriate and cost-effective to share financial and technical responsibility for a combined state and Federal measurement system for water level. As much as possible, the water-level measurement system should address the widest possible community needs while maintaining national standards.

Objectives

The overall objective of the present study was to define the requirements or needs of CESWG for water-level and associated information along the Texas coast. This report supersedes an interim working report submitted to CESWG on 30 September 1996. Major elements of this needs assessment are:

a. Locate and map existing CESWG tide staffs and document existing differential leveling connections with NGVD 29 for providing continuity with future water-level gauging.

b. Determine the general locations and numbers of water-level gauges required to support CESWG operations.

c. Identify the types and forms of water-level information, such as method of access during ongoing dredging activities and subsequent archival and retrieval methods.

d. Conduct proof-of-concept pilot projects to deliver real-time data on water level to CESWG offices.

e. Make recommendations on alternatives for establishing local project navigation datums that may not be related to the phase of the tide, related to mllw or appropriate chart datum, for CESWG use.

f. Document results in a report.

The needs assessment encompassed numerous tasks, including: coordination and information gathering with CESWG; inventory of existing CESWG tide staffs; assessment of the need for gauges according to present and possible future activities of the District, leading to development of a preliminary design plan and evaluation of alternatives; reconnaissance of existing and potential sites for water-level gauges; development of recommendations for water-level measurement and communications hardware; and general guidance on time and costs for implementing the recommended plan.

Scope of this Report

Chapter 1 of this report contains the background and objectives of the study. Water-level definitions and the character of the tide along the coast of Texas are discussed in Chapter 2, which includes concepts and nomenclature used throughout the report. Present water-level measurements available along the coast of Texas are given in Chapter 3. Chapter 4 describes communications alternatives for supplying real-time, voice-reported, and archived data to the CESWG. Chapter 5 describes the preliminary design of a water-level network aimed to provide real-time data to the District, as well as to give general access to the database. Chapter 6 contains a summary with main conclusions and recommendations. Appendices contain listings of detailed information developed in this needs assessment.

2 Water Level Definition, Measurement, and Properties

This chapter introduces basic nomenclature related to tidal datums and water-level measurement. Some typical characteristics of the water level observed on the Texas coast are compared to those from tide records on the Atlantic Ocean and Pacific Ocean coasts of the United States. The material is intended to provide a background for further technical discussion and to serve as motivation for establishing an appropriate navigation datum for the inland coastal waterways of Texas.

Historical Setting

Tidal datums and their application have been an issue in the United States since the founding of the nation. Both the need to establish a line of delineation between the land and sea interface and the appropriate method for determining the proper elevation were addressed early by the nation.

In 1807, the U.S. Congress assigned to the Coast and Geodetic Survey the tasks of delineating the sea-land interface and displaying it on charts (Shalowitz 1964). That agency, apparently having most experience on the U.S. east coast (where the astronomical tide is very regular), concluded that the most appropriate way of determining that interface or line would be by measurements of the rise and fall of the tide. This procedure entailed setting of a tide gauge, which was connected by differential leveling to fixed points on the land that could be used by engineers to survey the sea-land interface for charting. These procedures have

essentially continued, with some modification, throughout the history of the country. Eventually, a national network of permanently operating water-level measurement stations was established to support the charting activity.

Long-term tidal measurements from the U.S. Coast and Geodetic Survey were the basis for establishing a boundary indicating ownership between private upland and sovereign submerged lands (the landmark case Borax Consolidated, Ltd. vs. Los Angeles, circa 1935; see Shalowitz (1964)). The result of this decision by the U.S. Supreme Court was carried over by the state courts to be the accepted method for dealing with boundary issues. An 18.6-year water-level record, which corresponds to a complete cycle of progression of the moon's nodes along the ecliptic (described by Meton in the fifth century before Christ), is believed to account for all the astronomical variations in the ranges of the tide.

Also, it was believed for many years that the tides rose and fell periodically and the application of a mean high water was appropriate for all coastal waters. However, as more long-term tide stations have been operated throughout the United States, we have found that the astronomical gravitation is not always dominant. The tidal force is frequently exceeded by meteorological forces, acting both over the long term (seasons) and in the short term (hours and days through strong winds and changes in air pressure accompanying passage of weather fronts). Meteorological forcing can be particularly significant in shallow-water bodies, such as along the Texas coast. Observations from the TCOON have clearly shown that tidal datums established through traditional procedures are not well-suited within the bays and estuaries along the Texas coast for boundary, regulatory, or navigational purposes.

Water Level and Tidal Datums

This section reviews key concepts and notation relevant to the needs assessment. Definitions of tidal datums and associated nomenclature and concepts can by found in the NOS "Tide and Current Glossary" (Hicks 1989), in a USACE Special Report (Harris 1981), in the USACE Engineer Manual entitled "Water Levels and Wave Heights for Coastal Engineering Design" (USACE 1989), and in the EM entitled "Hydrographic

Surveying" (USACE 1991). A concise but authoritative overview of tidal datums and their various uses is given in Hicks (1985, 1986).

Basic concepts of tides and tide measurement

The tide is defined by NOS as the periodic rise and fall of the water resulting from gravitational interactions between the sun, moon, and earth (Hicks 1989). The term "tide" refers to the astronomically forced changes in water level, which is deterministic or predictable. Astronomical or *daily tide* should be distinguished from other contributions to changes in water level, including meteorological forcing (seasonal changes in sea level, changes caused by daily wind or to passage of weather fronts, etc.), terrestrial inputs (rain runoff or river discharge), and atmospheric forcing (change in air pressure). The distinguishing of periodicity produced by astronomical forcing and by diurnal and longer-term wind forcing, for example, has not been well addressed in tidal datum definition. Similarly, the distinguishing of variation in daily water (tidal) level and in annual water elevation does not seem to have been well addressed in the United States with regard to definition or determination of a navigation datum. In the following, standard NOS definitions for selected tidal datums are given for reference in this report.

Low water is the minimum height reached by a falling tide. Low water occurs according to the periodic tidal forces and the acting meteorological, hydrologic, and oceanographic conditions. For tidal datum computation, the minimum height is not considered a low water unless it contains a tidal low water (Hicks 1989).

Mean high water (mhw) and **mean low water** (mlw) are, respectively, the averages of all the high-water heights and low-water heights observed over the NTDE. For stations with time series shorter than 19 years, simultaneous comparisons with a control station are made to determine the equivalent datum of the NTDE. Also, strictly speaking, to be counted as a high, each high water must be 0.10 ft or more above, and must occur 2 hr or more later than the adjacent low waters. Analogous considerations hold for definition of low waters.

The **mean range of tide**, denoted as "Mn" by NOS, is the difference in height between mhw and mlw. Thus, Mn corresponds to a tidal range

defined in terms of *daily* highs and lows and does not include such changes as a seasonal variation in water elevation. Note that Mn is not a tidal datum because it is not an elevation or level, but a range. **Mean Tide Level** (mtl) or "half tide level" is a tidal datum and is the arithmetic mean of mhw and mlw. The mtl may lie above or below msl by an amount depending on the relative amplitudes of the diurnal (having a period of approximately 1 lunar day) components of the tide.

Mean higher high water (mhhw) and **mean lower low water** (mllw) are, respectively, the averages of the higher high water heights and lower low water heights of each tidal day (or lunar day; 24.84 solar hr) observed over the NTDE. For example, if there are two lows in a tidal day, the lower of the two is used to compute mllw for that day. The mllw is presently used by NOS as a nautical chart datum.

Tide gauge and tide station

A **tide gauge**, or water-level gauge in a more general sense, is an instrument for measuring the rise and fall of the tide or water level. Presently, acoustic gauges and pressure gauges are used as automated water-level measurement systems because of their reliability and capability to produce an electronic signal for convenient processing. These measurement systems also require little power and are suited for remote sites where the power unit must be self-contained. A **tide staff** is a simple form of tide gauge and consists of a vertical graduated staff from which the height of the water can be read visually.

A **tide station**, or water-level station in a more general sense, is the geographic location at which tidal or water-level observations have been made. The defining aspect of a tide station is the presence of a system of (tidal) benchmarks, which are fixed physical objects (typically, deep-driven rods) that serve as a reference for a vertical datum. The tidal benchmarks are central to water-level measurement because the relation between elevation of the land and water can be tracked through time, the benchmarks providing the fixed reference (in the absence of subsidence or crustal movement in general). Water-level measurement without reference to benchmarks cannot produce recoverable tidal datums.

Zoning

Zoning is a procedure in which the project area of a hydrographic survey is divided into sections or "zones" to account for differences in tidal ranges and phases within the area. In the hydrographic survey, adjustments or "reducers" are applied to the depth soundings, which are taken at all stages of the tide, to reference them to a common datum. The correction must also allow for the time differences between the survey area and the water-level gauge used for the control. Tidal zones are distinguished by keeping two properties, range of tide and phase of tide, within certain limits, typically 0.2 ft and 0.2 hr, respectively (Hicks 1989). However, as stated by Hicks (1989), "these limits are subject to change, depending upon survey accuracy, location, and tidal characteristics." In the case of Texas inland coastal waters, not only the astronomical tide, but also wind forcing, must be considered in the zoning.

Character of the Tide Along the Texas Coast

Characteristics of the tide along much of the Gulf of Mexico are different than those on the Atlantic Ocean and Pacific Ocean coasts. Even within the Gulf of Mexico, tidal characteristics are variable from one locality to another within short distances. Prior to the 1950s, there were only a few locations where long-term tidal measurements had been made. Although diurnal high and low waters occur only during the extreme north and south declinations of the moon, the tides were classified as diurnal in character. The mlw was therefore used as the reference datum for hydrographic surveys.

As more systematic tidal observations were made in the coastal waters of the Gulf of Mexico, it became evident that the classification of semi-diurnal tides for the entire Gulf was not defensible. Although many areas have two high and two low waters most of the time, there are nearby areas where only one high and one low water occur. This observation led to the creation of the Gulf Coast Low Water Datum (GCLWD) for the NOS Nautical Charts. The GCLWD is defined as: mllw when the type of tide is mixed, and mlw when the type of tide is diurnal. The National Tidal Datum Convention of 1980 (Hicks 1980) established one uniform,

continuous tidal datum system for all marine waters of the United States and replaced the GCLWD by mllw, among several other actions.

Figures 2-7 are plots of the year-long hourly water-level records at representative tide gauges on the Pacific, Atlantic, and Gulf coasts. These include two inland coastal stations of Texas, the South Padre Island Coast Guard Station located at the southern end of the Laguna Madre, and Packery Channel located at the northern end of the Laguna Madre near its entrance to Corpus Christi Bay. The figures are plotted to the mllw datum of each station, and the respective values of mhw and mlw are given in the upper right corners of the plots.

Figure 2 for Los Angeles, California, shows a clear signal of the approximate 14-day neap and spring tide cycle corresponding to the phases of the moon. By its definition as an average, there must be times when the water level falls below mllw; for Los Angeles, this occurs at a fairly regular periodic cycle corresponding to the times of spring tide, when the moon is either new or full. Ships waiting to proceed into or leave a port could consult tide predictions with reasonable confidence to determine safe clearance under keel for a given draft according to load. Overall, the water level at Los Angeles is fairly symmetric with respect to the mtl. Little seasonal trend appears in the yearlong record.

Figures 3 and 4 show yearlong records for Sandy Hook, New Jersey, and Fernandina, Florida. The water level is not as pronounced in spring-neap cycle as is that of Los Angeles, in part due to the mixed character of the tide and also to the action of storms on the gently sloping continental shelf of the Atlantic coast as compared to the Pacific coast. Water level falls below mllw in a somewhat less regular manner than at Los Angeles. A slight seasonal trend of lower waters in winter is observed. For the Atlantic- and Pacific-coast gauge records, the body of measurements stays well and regularly within the mean range of tide defined by the mhw and mlw lines drawn in the figures. At both locations, the deviation below mllw is typically 20 to 25 percent of the range.

In contrast to the Atlantic- and Pacific-coast water-level records, the record from Bob Hall Pier, Corpus Christi, Texas, on the Gulf of Mexico (Figure 5), is irregular, with the seasonal trend change in water elevation comparable to or exceeding the daily change in tide. Further, the deviation

below mllw is typically on the order of 50 percent of the range and sometimes equals or approaches the range in 1995. Although a spring-neap cycle is evident, local nonastronomical tidal forcing makes the cycle appear irregular. Similar observations hold for the South Padre Island Coast Guard Station gauge, which is located near the Brazos-Santiago Pass and ship channel (Figure 6).

Figure 7 displays a year-long record for Packery Channel, which is located just off the GIWW in Corpus Christi Bay, on the bay side of Padre Island and nearly opposite to the Bob Hall tide gauge. Strong seasonality in the water level is apparent, and, in 1995, the water level remained below mllw for approximately 1 month starting in mid-January. Further, the deviation in water level below mllw was typically equal to the mean range of tide and even reached twice the mean range below mllw. This record indicates a need for a navigation datum that accounts for seasonal lows and that is not based on a simple average of daily water-level lows.

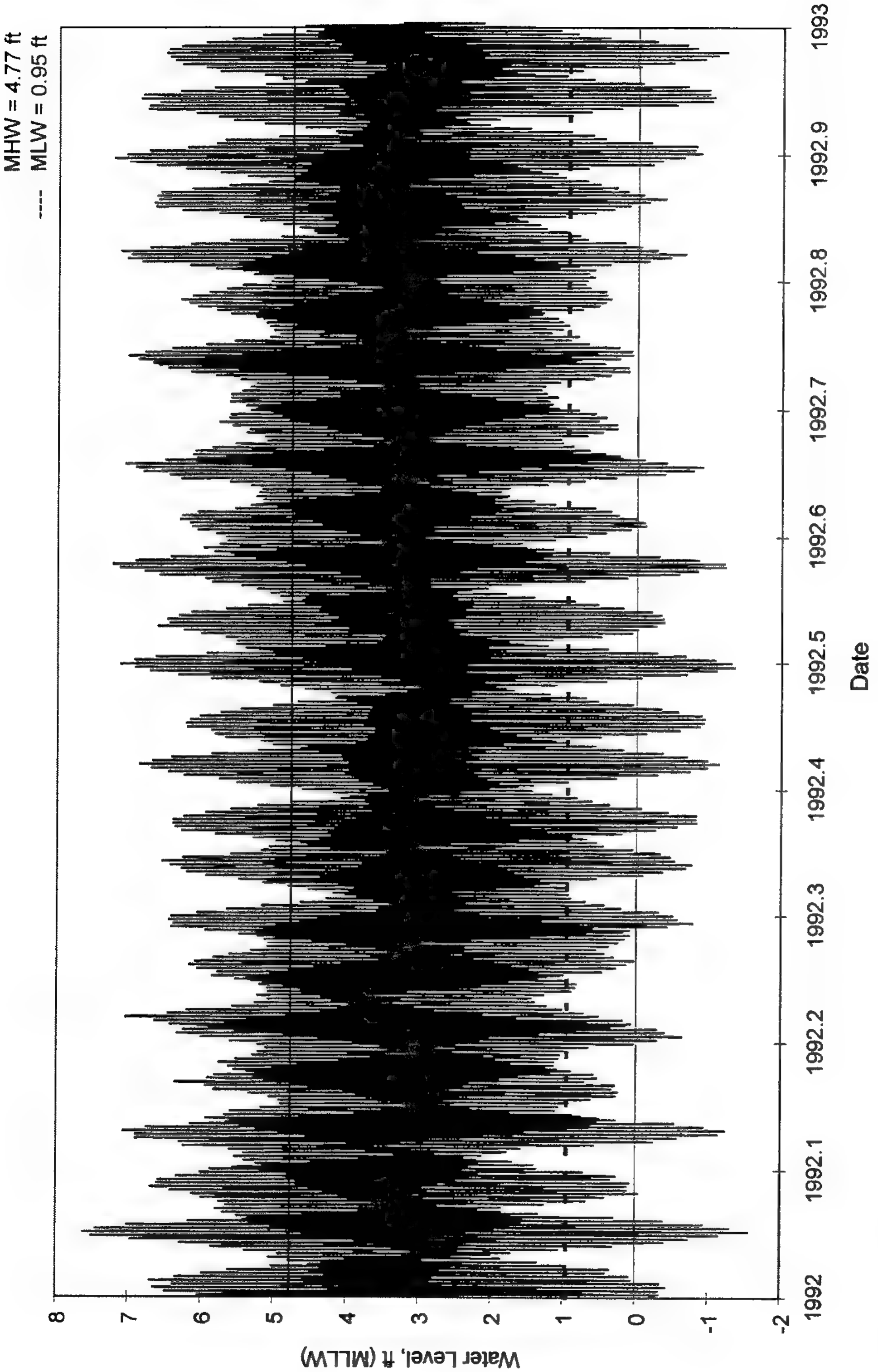

Figure 2. 1992 water level for Los Angeles, California

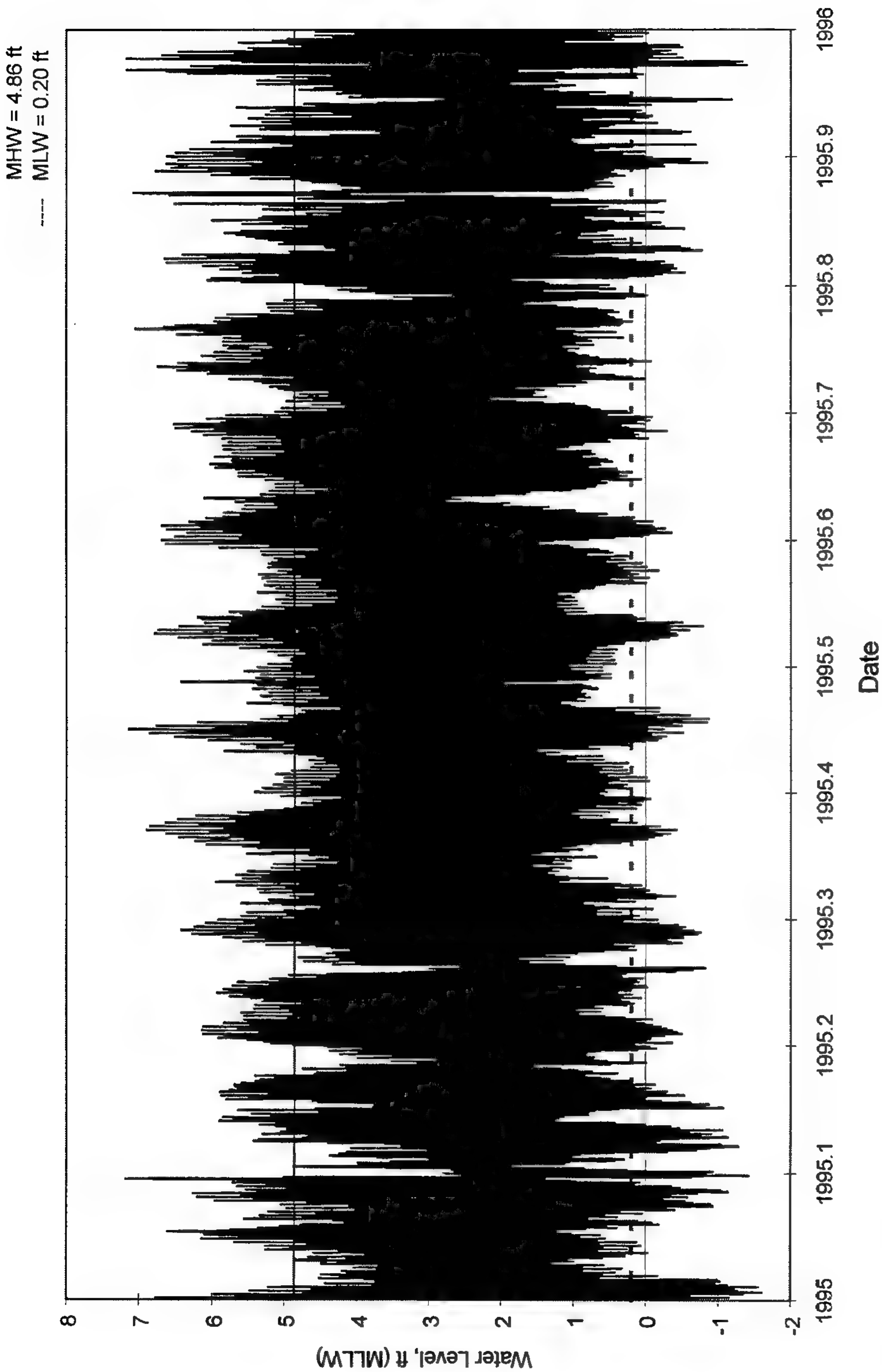

Figure 3. 1995 water level for Sandy Hook, New Jersey

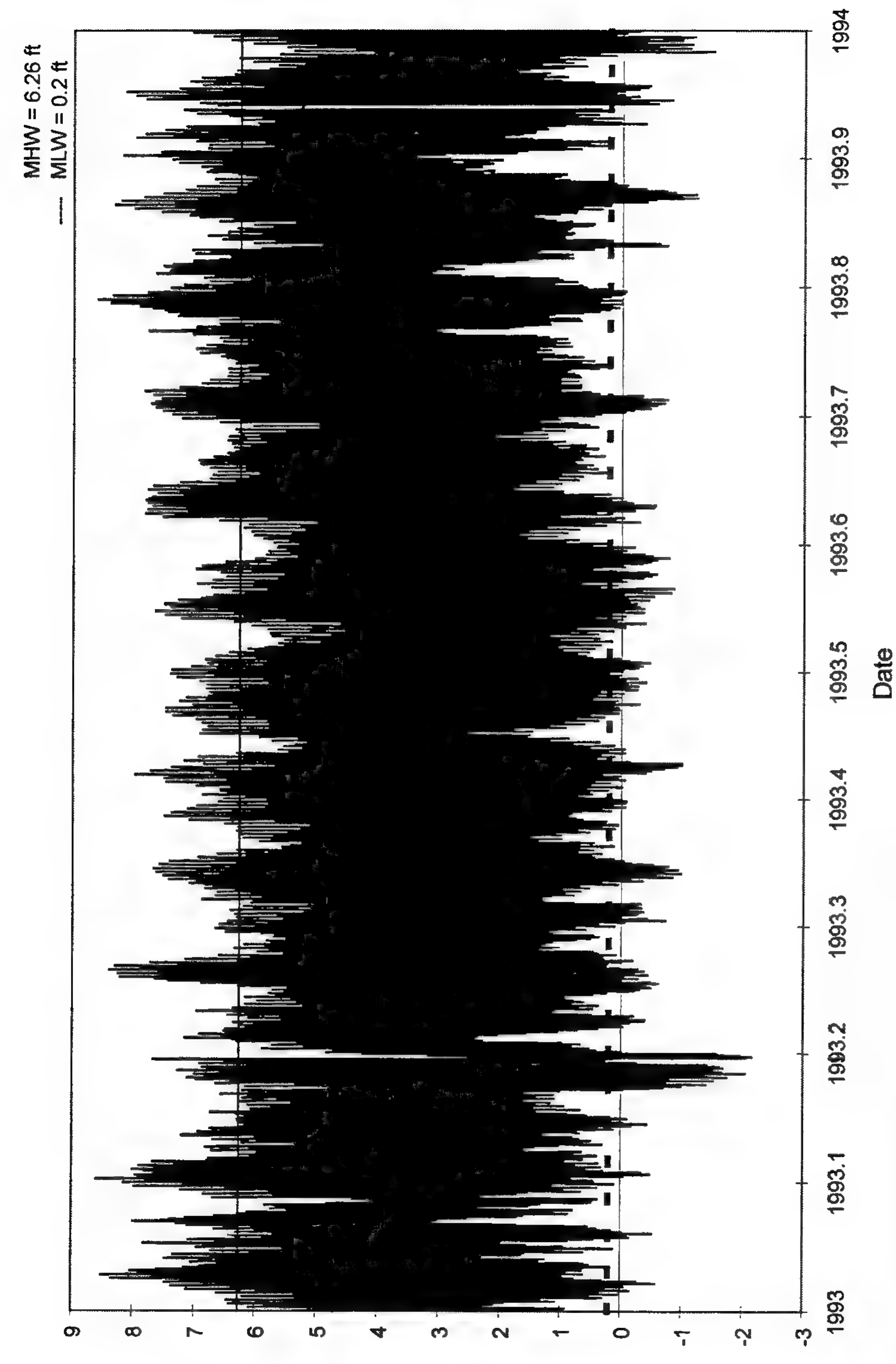

Figure 4. 1993 water level for Fernandina, Florida

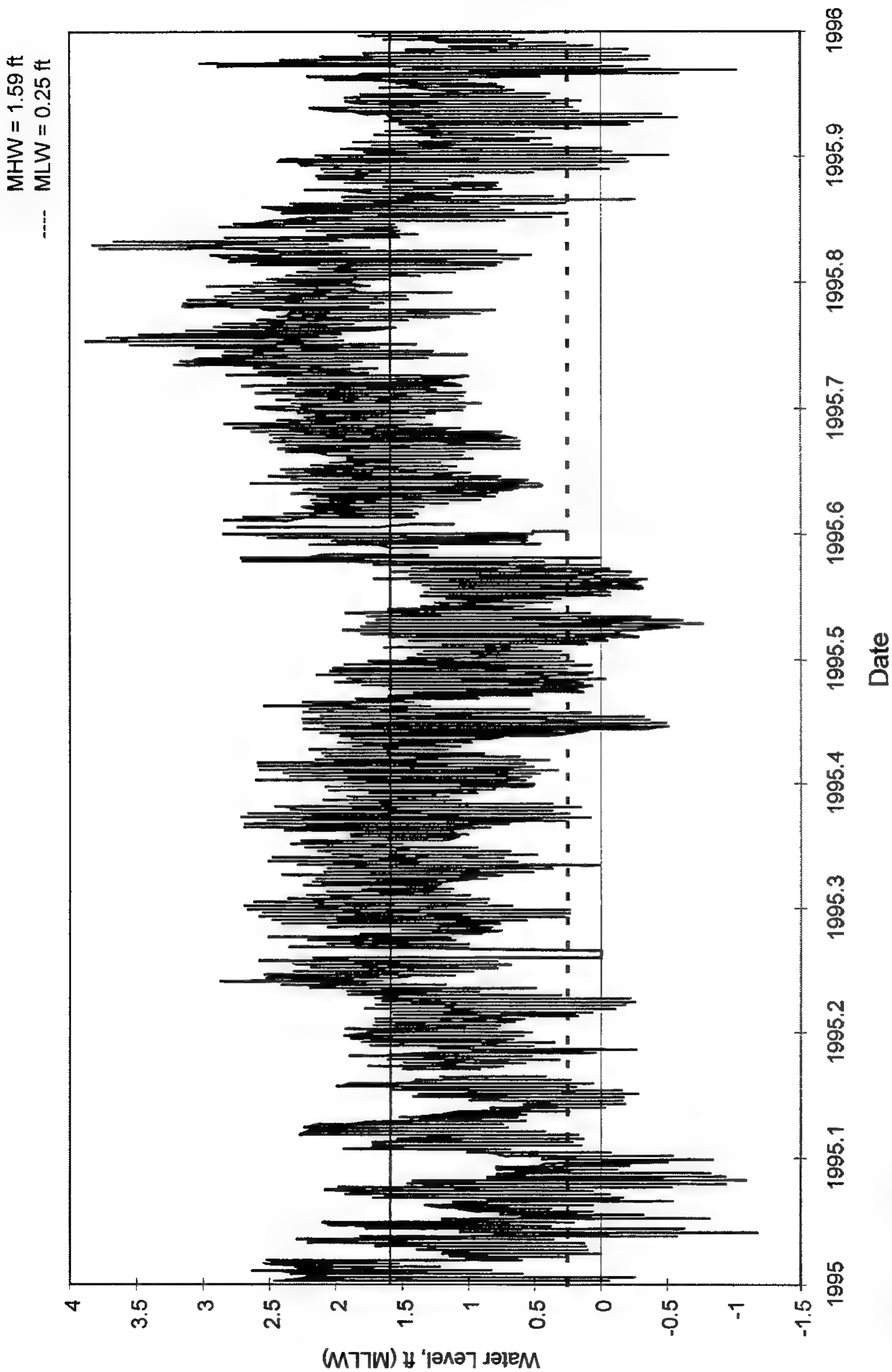

Figure 5. 1995 water level for Bob Hall Pier, Texas

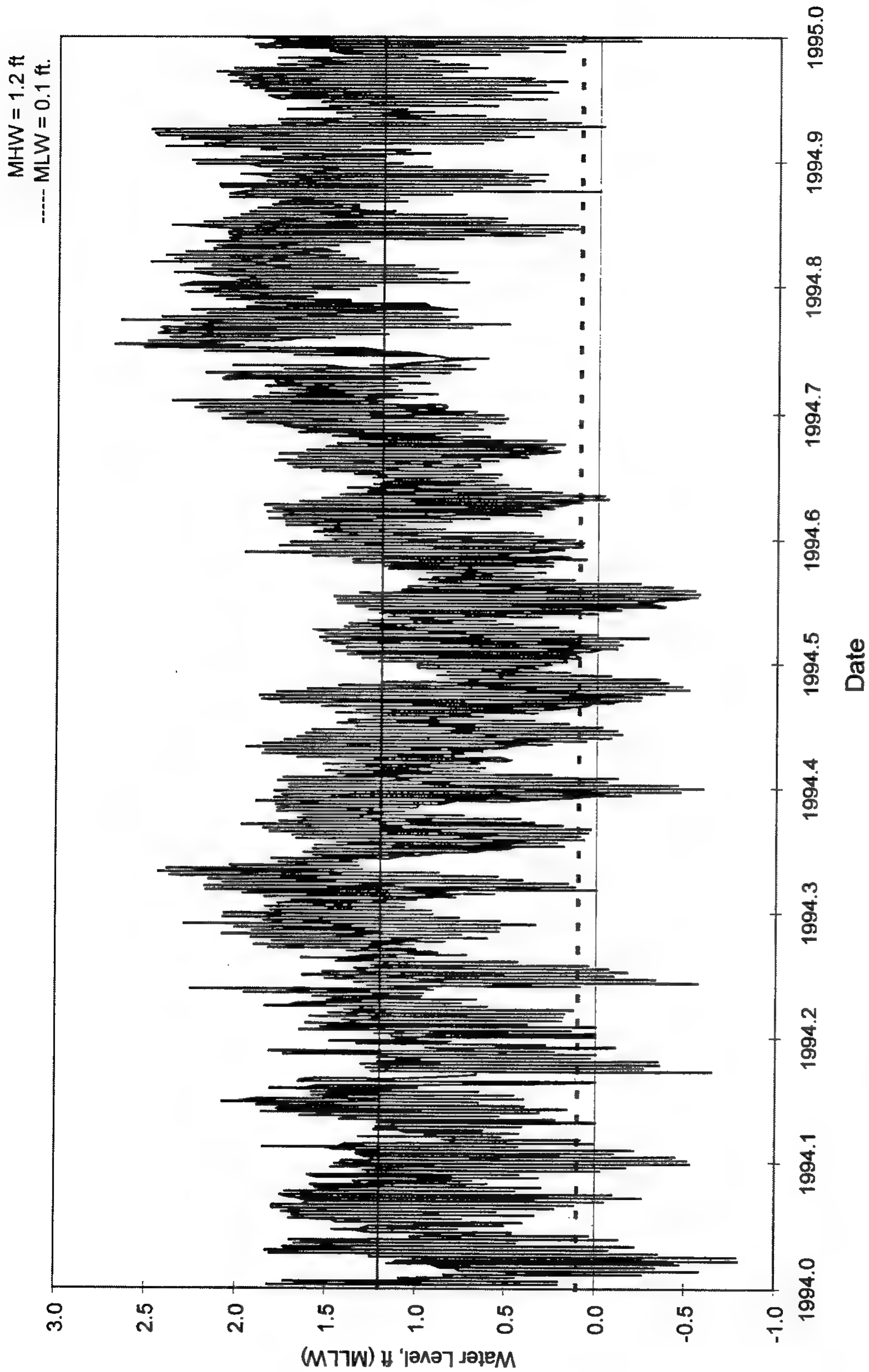

Figure 6. 1994 water level for S. Padre Island Coast Guard Station

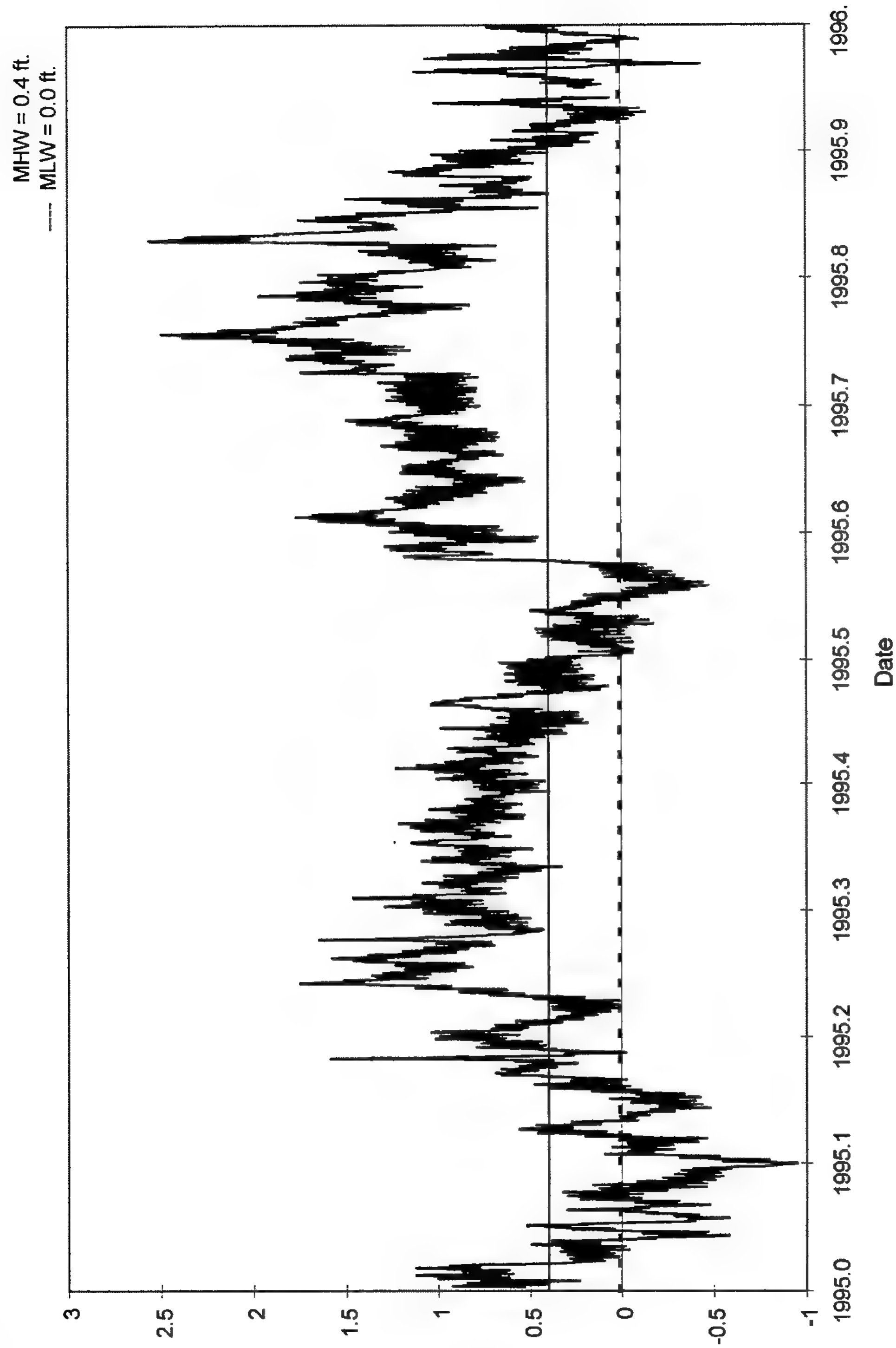

Figure 7. 1995 water level for Packery Channel, Texas

3 Present Water-Level Measurement Networks Along the Texas Coast

This chapter summarizes the status of TCOON water-level measurement and of CESWG water-level measurement as practiced by its field offices and hydrographic survey parties. The status is current to September 1996, with some updates. The summary introduces basic District operational needs as an outcome, which would include the needs of Government contractors.

TCOON Capabilities

The TCOON presently consists of approximately 40 water-level stations. On or near the coast, eight NOS gauges serve as long-term control stations. Table A1 in Appendix A summarizes the status of the TCOON and NOS tide stations.

Present Galveston District Field Practice and Identified Needs

The CESWG tide staffs are presently central to its hydrographic surveys. Examples of two staffs are given in Figures 8 and 9. It is standard procedure to take the survey boat to a tide staff to record water level at the start of the day's survey (typically early morning), mid-morning, noon, mid-afternoon, and when quitting for the day. At the tide staff, the survey boat will check its echo sounder and note the elevation of the water on the staff and the time. In surveys of long channels, during a

typical survey day, the boat may have to visit several different tide staffs located along the channel, depending on the rate of coverage of an area, or station a survey crew member at the nearest staff to regularly report water elevation via radio. A high density of staffs in some water bodies probably reflects as much the need to reduce transit time to and from staff visits as recognition that the water-level elevation changes along a water body.

Boat visits to the staffs can consume substantial time in going off station, remaining at the staff for several minutes, and then returning on station. An operational problem sometimes encountered is difficulty in visually reading the tide staff in moderate waves and wind, which can cause trouble in keeping the boat stationary at the staff.

The tide staffs, which are typically mounted on timber survey platforms, channel markers, bulkheads, etc., are routinely replaced as the mounting structures are destroyed by barges or other vessels. Re-installation of the staffs at the correct elevation often requires performance of a level survey (if the tide station is near land or a survey table) or knowledge of the water level based on a reading made at a nearby staff. Figure 10 shows a staff being replaced by a Southern Area Office surveyor.

In discussions with CESWG hydrographic survey party personnel, several operational needs were identified. Survey boats could remain on station and continue surveying if the operators could simply phone to a gauge and obtain the water level. The information reported by the gauge must be in standard units (feet, local time), and a repeat option should be available because of occasional noise or loss of attention due to other duties on the survey boat. The water level should be reported in terms of the CESWG navigation datum (presently mtl), or a table for converting from the reporting datum to the navigation datum should be provided (e.g., mllw to mlt).

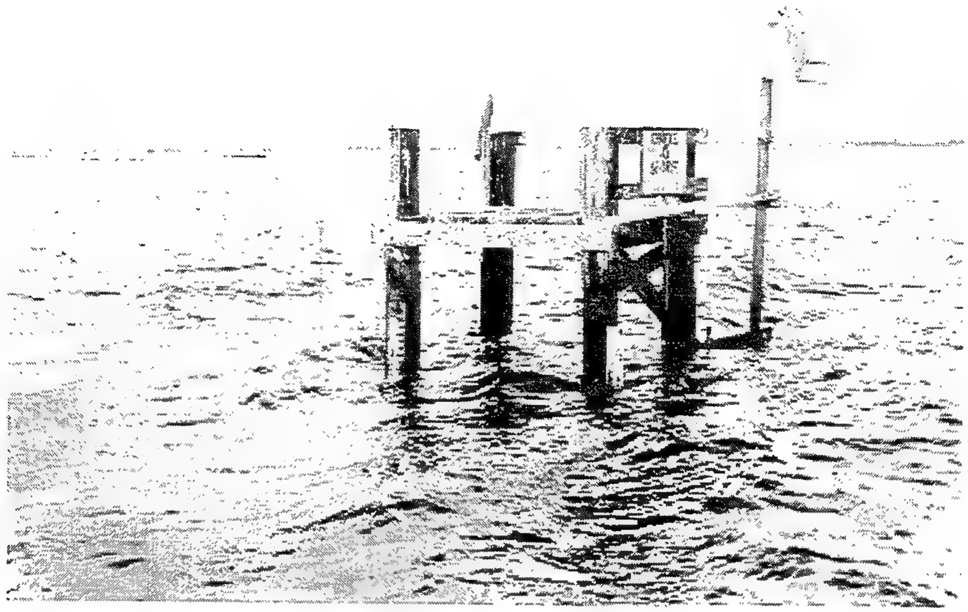

Figure 8. Tide staff mounted on survey table at Channel to Victoria (see Staff 8, Chart G, Appendix B). A dredging contractor's staff is mounted on the third pile from left

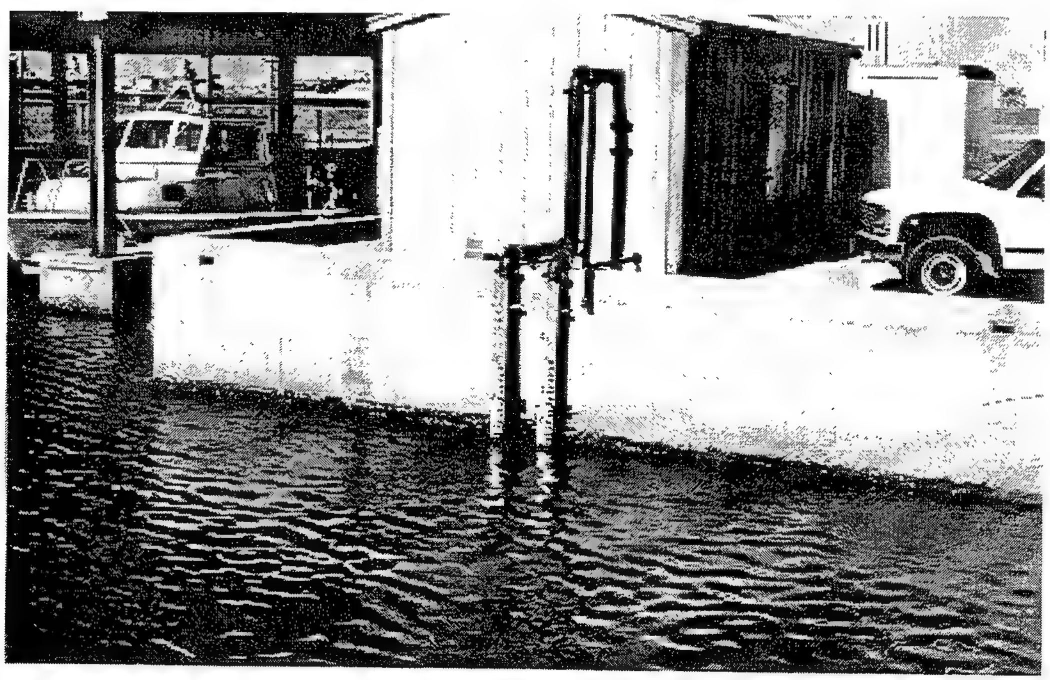

Figure 9. Freeport Entrance Channel at the U.S. Coast Guard Station, Surfside (see Staff 3, Chart E, Appendix B). The staff on the left is referenced to mlt, and the staff on the right is referenced to msl

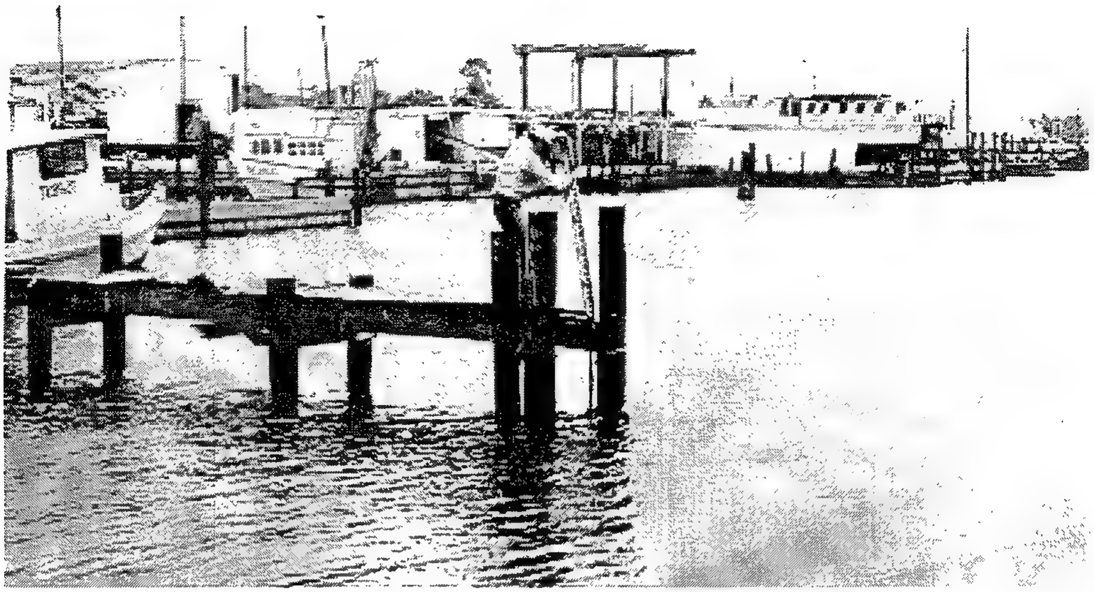

Figure 10. Staff being replaced at Fulton Harbor public boat ramp, Aransas Bay (see Staff 5, Chart G, Appendix B)

At the office, the survey parties would benefit from ready availability of a hard copy of the water-level record during the time they were onsite for confirmation of the voice record and for documentation. The most convenient way would be through facsimile; however, they would have interest in downloading via the Internet, such as from a World Wide Web (WWW) site, if they received training and equipment to do so.

In addition, the CESWG and its field offices are routinely asked to provide water-level data or these offices themselves need water-level data for varied reasons, including response and analysis of boating accidents and responses to oil spills. Convenient access to hard copy or archived data reaching back several months would usually satisfy most such needs.

Finally, interest was expressed in certain topics in related areas. A primer (handbook) providing explanations of water levels and their inter-relations was thought to be useful if not essential. The water-level information should be given in local time and to the navigation datum, not, say, to Greenwich Time or to an arbitrary staff datum that requires further conversion. Information on wind and current, although not typically

entering directly in routine surveying operations, was sometimes needed for evaluating claims of bad weather by dredging contractors and for analyzing the circumstances concerning boating accidents.

In the offshore, information on wave height, period, and direction, as well as water level, would be valuable for confirmation of weather days that halt dredging. Dredgers sometimes appear to have to halt due to longer period wave motions than just short-period surface waves; a wave gauge might be able to determine the conditions when this problem occurs. Finally, some interest was expressed in being able to obtain predictions of the tide, both for planning routine operations and for emergency planning during hurricanes and storms.

Locations of Galveston District Tide Staffs

After creating preliminary maps showing general locations of tide staffs based on information provided by the CESWG Area Offices, 13 days of field reconnaissance were conducted during September and October 1996, of the CESWG tide staffs from Port Arthur to Brownsville. The locations (geographic coordinates and description) of the staffs were determined by differential global positioning system (DGPS) or global positioning system (GPS) survey, depending on satellite coverage at the time the particular stations were visited.

A list of the locations of 166 CESWG tide staffs identified during the survey is contained in Appendix B. In several cases, the tide staffs were missing at the time of the survey, and station coordinates (for staffs to be later replaced) were obtained based on knowledge of the former staff location as provided by the Area Office field personnel who served as guides during the field visits. Maps showing tide station locations were generated as shown in Charts A-J in Chapter 5 and were designed to cover areas of the coast corresponding to areas covered by specific NOAA charts.

MLT and NGVD Difference

The differences between the mlt datum and NGVD 29 are listed in Table 1, as provided by personnel of CESWG. Many of these differences were determined in the 1960s and 1970s.

Table 1
Elevation Difference Between mlt and NGVD 29

Water Body	Reach	mlt as Feet Below NGVD 29
GIWW-Main Channel	Port Arthur - High Island	1.1
GIWW-Main Channel	High Island – Bolivar	0.5
GIWW-Main Channel	Galveston – Matagorda	1.4
GIWW-Main Channel	Matagorda - Port Mansfield	1.0
GIWW-Main Channel	Port Mansfield - Port Isabel	0.9
Sabine Neches Waterway	Sabine – Orange	0.8
Houston Ship Channel	Bolivar – Lynchburg	1.4
Houston Ship Channel	Lynchburg - Main Street	1.1
Cedar Bayou	Cedar Bayou Channel	1.4
Trinity River	Trinity River Channel	1.0
Ear Creek	Ear Creek Channel	1.3
Dickinson Bayou	Dickinson Bayou Channel	1.4
Galveston Bay	Galveston Harbor – Texas City Chnl.	1.4
Chocolate Bayou	Chocolate Bayou Channel	1.4
Bastrop Bayou	Bastrop Bayou Channel	1.4
Freeport Harbor	Freeport Harbor	1.4
Brazos River - Colorado River	Brazos River Floodgates - Colorado River Locks	1.4
Palacious - La Quinta Channel	Palacious - La Quinta	1.0
Brazos Island Harbor	Brazos Island Harbor – Brownsville	0.9
Port Isabel	Port Isabel	0.9

4 Communications Alternatives

This chapter is concerned with communications alternatives for real-time reporting and for access to archived data in a database. New equipment and capabilities are constantly reaching the market, so an existing-market search would need to be done at time of implementation.

Real-Time Reporting

Table 2 compares alternatives presently available for real-time voice reporting of water level and related information. Certain instrument manufacturers sell proprietary turnkey measurement systems that include radio communication, which were not investigated here.

Table 2
Features of Selected Voice-Reporting Systems

Feature	Sutron Board	Sphere Reporter	Dialogic Netware	Voice Modem UNIX
Annual maintenance costs	Phone Charges	Phone Charges	PC Cost, phones	PC Cost, Phones
Capability (# Users)	1	2 (Phone/Radio)	Up to 32	Up to 32
Expandability	Minimal	Moderate	Minimal	Good
Stand-alone or networked	Stand Alone	Stand Alone	Networked	Networked
Type of connection	Cell/Land Phone	Cell/Land Phone, plus marine radio	Cell/Land Phone	Cell/Land Phone, Data Radio
Voice vocabulary	Minimal	Moderate	Limited	Good
Voice quality	Minimal	Good	Good	Good
Voice speed	Minimal	Moderate	Moderate	Good
Fax or other medium	Text Terminal	None	Text Terminal	Fax, Text Terminal, Graphics

Summary descriptions of the equipment are as follows:

Sutron board: Modular circuit board that plugs into any Sutron tide gauge station. Access is via telephone. If the gauge is at a remote location, a cellular phone with land line simulator is required.

Sphere reporter: Small external circuit connects to any Sutron tide gauge via data port. Access is via telephone or marine radio. If the gauge is at a remote location, a cellular phone with land line simulator is required. The marine radio will provide a report automatically every 5 to 10 min on VHF Channel 13. The manufacturer is located in Australia, and some difficulty was noted in provided changes in voice vocabulary; however, the Sphere system appears to be very flexible.

Dialogic Netware: Centralized personal computer (PC) is used. Users call this PC to hear high quality stored speech. The PC communicates with tide gauges via a separate phone or by data radio. This alternative is more costly than either the Sutron board or Sphere reporter, but higher speech quality, alerting capabilities, etc., can be built in. Altering the messages requires recording new phrases in a studio and installing them on the system.

Voice Modem/UNIX: This is an evolution of the Dialogic Netware system and is currently being actively developed at the Conrad Blucher Institute (CBI) for its "FlowInfo" systems. Users call a central PC to hear high-quality digitized speech. The PC communicates with tide gauges via a separate phone or by data radio. Changes to the messages are conveniently made by editing text files. Such changes may be done locally or remotely via secure dial-in modem.

Recommendations and Costs

At present, the following recommendations are made, but should be reviewed and revised prior to implementation. To access a particular tide gauge via telephone, a Sutron board is recommended. If radio reporting is desired, a Sphere reporter would be installed. To provide voice reports to telephone callers from gauges in a particular area, installation of a centralized PC is recommended. Currently, CBI would use the Voice

Modem/UNIX system. Table 3 gives estimates of costs of hardware and labor, exclusive of labor for procurement, testing, and initial deployment.

Table 3
Estimated Cost of Stand-Alone (per gauge) Voice-Reporting Systems

System	Base Cost	Phone	Labor	Total	Remarks
Sutron Board	$1,200	$250 (Land)	$1,000	$2,450	Monthly charges
Sutron Board	$1,200	$2,000 (CMT)[1]	$1,000	$3,200	Per minute fee
Sphere	$1,200	$ 250 (Land)	$1,000	$2,450	Monthly charges
Sphere	$1,200	$2,000 (CMT)[1]	$1,000	$3,200	Per minute fee
Radio[2]	$1,000[2]				

Includes phone, batteries, solar panels, enclosure, antenna, landline simulator, etc.
Does not include overhead, handling, and other indirect costs.
[1]Includes radio, antenna, batteries, solar panel, enclosure, antenna. Range is 5-10 miles per FCC rules.
[2]Radio may be added to a Sphere with either Land or CMT phone, or installed without either type of phone.

Centralized PC System:

Because of a wide variety of possible configurations, costs will vary widely. A rough estimate of costs is as follows, not including indirect costs:

Basic PC, speech hardware	$4,000
Operating system	FREE (LINUX)
Speech software	$2,000
Basic installation	$1,000
Phone company installation (3 lines)	$ 750
Data radio system (to retrieve gauge data)	$1,500
Total	$9,250

(approximate)

Table 4 gives a listing of tide gauges possessing voice-reporting capability as of 30 December 1996.

Table 4 Gauges With Speech Capability, December 1996			
Station Name	**Station ID Number**	**Phone Number**	**Location (Lat/Long)**
Mesquite Point	877 05391	409-781-9831	29 46.0' / 93 53.7'
Chocolate Bayou	877 17081	409-781-7195	29 12.7' / 95 12.4'
Eagle Point	877 10131	409-656-4069	29 29.9' / 94 54.7'
Rollover	877 09711	409-781-7193	29 30.9' / 94 30.8'
Morgan's Point	878 06131	713-470-9739	29 40.6' / 94 59.1
Beaumont	877 05951	409-656-2670	30 05.7' / 94 05.4'
Texas State Aquarium at Harbor Bridge	CBI90008	512-881-1266	27 40.8' / 97 23.5'
Ingleside	877 52831	512-776-6934	27 49.3' / 97 12.5'
Port Aransas	877 52371	512-815-4049	27 50.4' / 97 04.4'

All gauges presently use the Sutron board and report water levels to mllw.

Access to Archived Data

Historic and daily data for the TCOON and NOS gauges in Texas may be retrieved via the Internet using any standard WWW browser package. The data are typically as recent as 3 hr old when received at CBI. Options which may be selected by the user include: (a) data from previous week for all sensors at a specified station; (b) any specified time period - days, weeks, months, or years; and (c) multiple stations per graph to compare tide signals. Other capabilities may be added on request.

CBI maintains an up-to-date list of Universal Resource Locators and system capabilities. Two example screens are shown in Figures 11 and 12. Capabilities of the TCOON web page are constantly being improved.

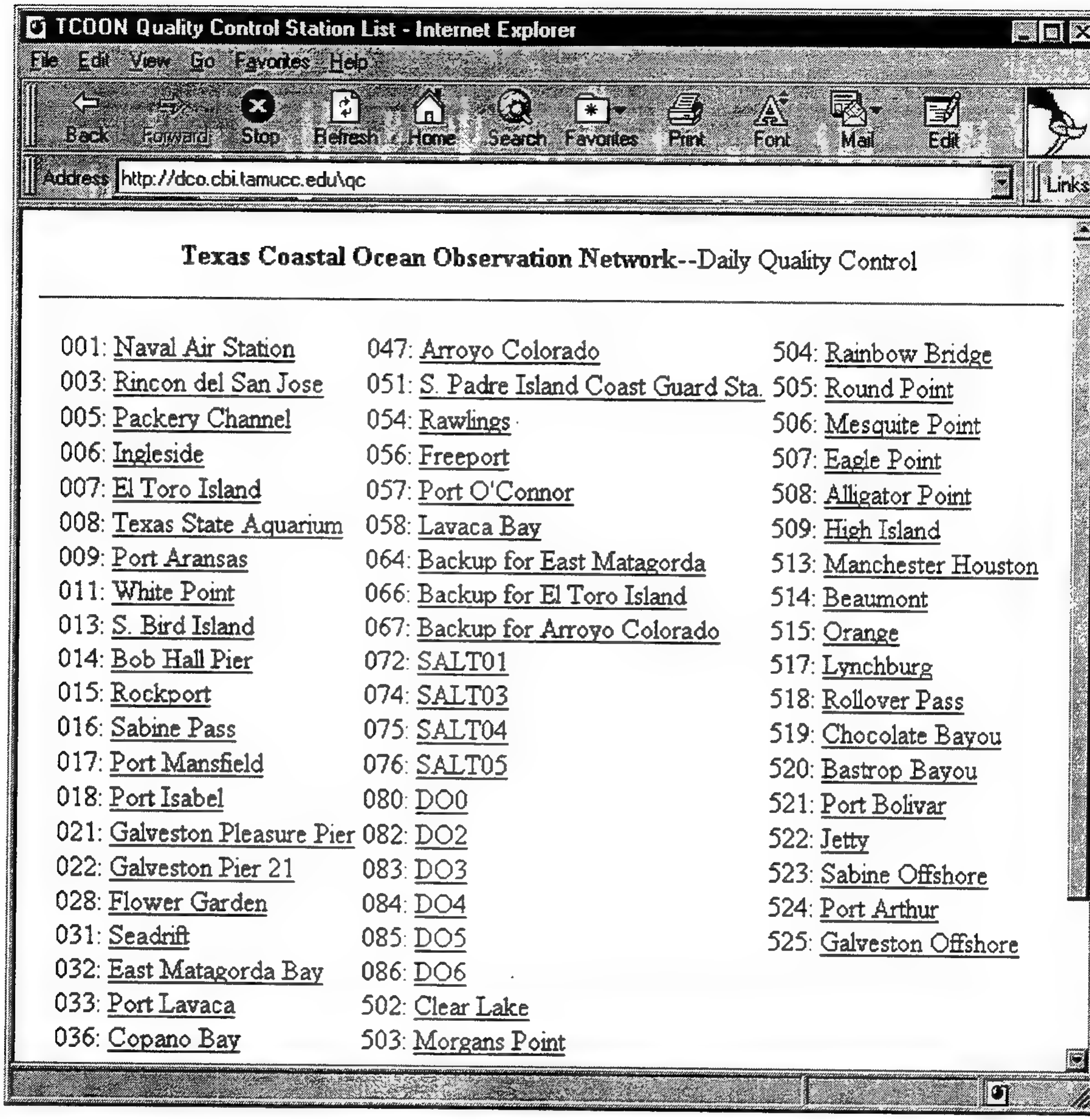

Figure 11. TCOON quality control station list

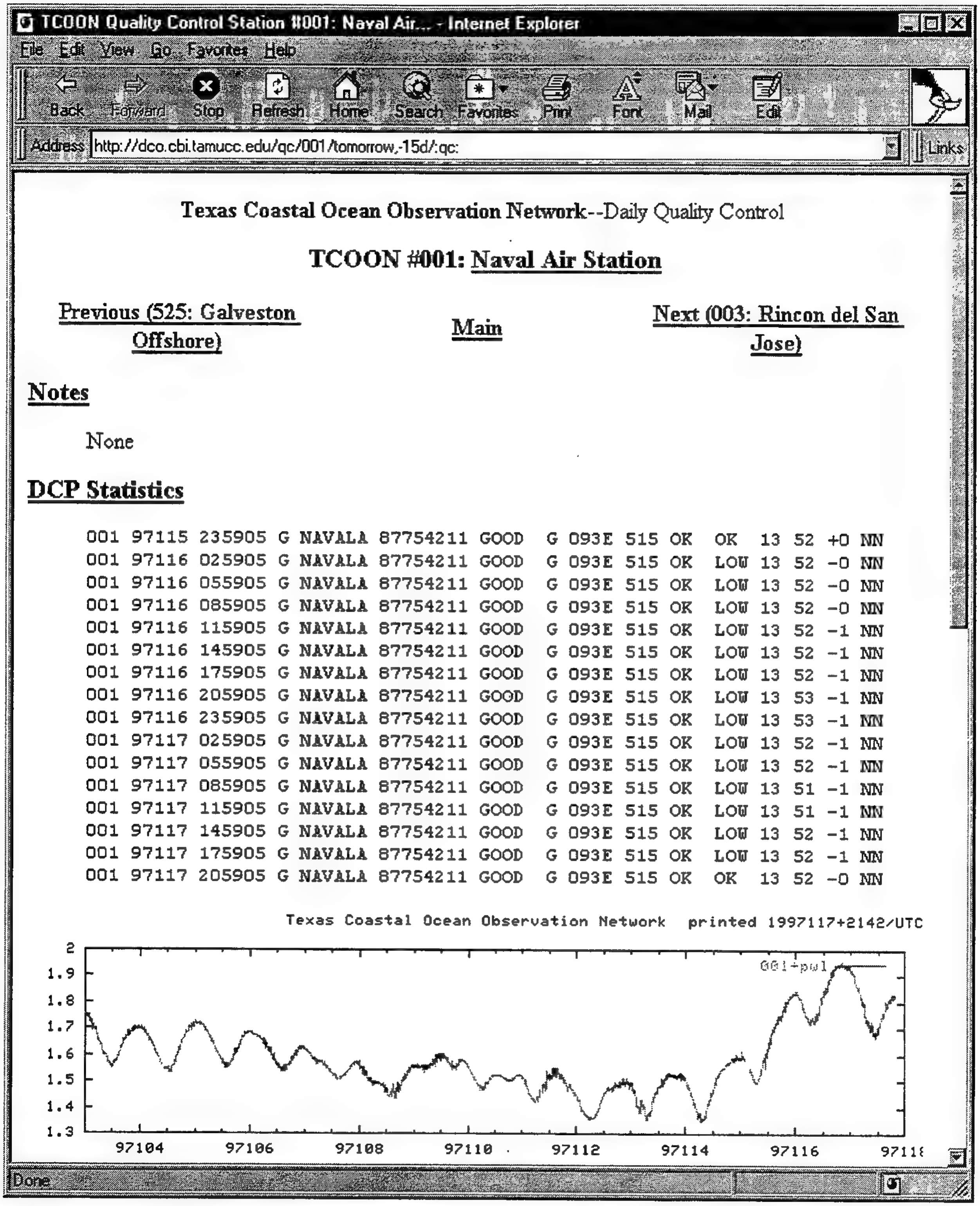

Figure 12. TCOON quality control station 001: Naval Air Station

5 Consideration of an Expanded Network

This chapter contains information for guiding future detailed planning of the TCOON for CESWG needs.

Present Status of Network

The first step in designing a network is to obtain all historic data available within the area of interest. This information has been obtained and is summarized in Table 5. Maps, which follow in Figures 13-22, show the locations of the gauges, as well as selected CESWG tide staffs. A review of the historic data and the data from the TCOON system reveals a lack of sufficient information for navigational or regulatory purposes for several key areas. These are addressed in the final chapter giving conclusions and recommendations.

Table 5

Summary of Water-Level Stations on the Texas Coast and Inland Coastal Waters (as of September 1996)

Station Name	NOS Station Number	TCOON Number	Installed	Removed	Water Body	mhw ft*	mlw ft*	Observed Lowest ft*	Mn ft	NGVD '29 Tie
A. NOS Chart Number 11301										
Port Isabel	877 9770 1	18	2/91	--	Laguna Madre	1.33	0.19	-2.96	1.14	N
South Bay, Clark Island	877 9768 1	024	9/91	1/12/93	South Bay	1.30	0.20	--	1.10	N
South Padre Island	877 9750 0	--	6/58 12/80	6/14/79 5/5/94	Brazos Santiago Pass	1.51	0.20	-1.81	1.31	Y
S. Padre Island, CG Stn	877 9748 1	51	4/93	--	Laguna Madre	1.20	0.10	--	1.10	N
Queen Isabella Causeway	877 9739	--	10/73	5/2/78	Laguna Madre	1.17	0.12	-1.11	1.05	N
Queen Isabella Causeway	877 9724 0	--	12/76	4/27/78	Laguna Madre	1.24	0.16	-1.22	1.08	Y
Arroyo Colorado	877 9038	47	11/92	--	Laguna Madre	NON-TIDAL				N
Port Mansfield	877 8490 1	47	2/90	--	Laguna Madre	NON-TIDAL				N
B. NOS Chart Numbers 11304, 11306, and 11308										
Rincon del San Jose	877 7812 1	3	3/90	--	Laguna Madre	NON-TIDAL				N
El Toro	877 7562 1	7	3/90	--	Laguna Madre	NON-TIDAL				N
Yarborough Pass	877 6687 1	4	3/90	--	Laguna Madre	NON-TIDAL				N
C. NOS Chart Number 11307										
South Bird Island	877 6139 1	13	9/91	--	Laguna Madre	NON-TIDAL				N
CC Bob Hall Pier	877 5870 1	14	5/89	--	Gulf of Mexico	1.59	0.25	-1.65	1.34	N
D. NOS Chart Numbers 11308 and 11309										
Packery Channel	877 5792 1	5	3/90	--	Laguna Madre	0.37	0.01	-1.04	0.36	N
Shamrock Island	877 5422	39	3/92	--	Corpus Christi Bay	0.60	0.00	--	0.60	N
CC Naval Air Station	877 5421 1	1	11/89	--	Corpus Christi Bay	0.67	0.03	-0.40	0.64	N
Lawrence Street T-Head	877 5351 0	2	12/88	4/4/91	Corpus Christi Bay	0.60	0.00	--	0.60	N
Texas State Aquarium	877 5296 1	8	6/90	--	Corpus Christi Bay	0.60	0.00	--	0.60	N
Port Ingelside	877 5283 1	6	5/89	--	Corpus Christi Bay	0.60	0.00	--	0.60	N
Port Aransas	877 5237 1	9	5/90	--	Aransas Ship Chnl	0.90	0.10	--	0.80	N
White Point	877 5188 1	11	7/90	--	Nueces Bay	0.60	0.00	--	0.60	N
E. NOS Chart Numbers 11313 and 11314										
Rockport	877 4770 1	15	3/91	--	Aransas Bay	0.35	0.00	-1.98	0.35	N
Bayside	877 4652	30	2/93	--	Copano bay	0.40	0.00	--	0.40	N
Indian Head Point	877 4527	37	11/92	--	St. Charles Bay	0.40	0.00	--	0.40	N
Goose Island	877 4522	35	6/92	--	St. Charles Bay	TO BE CALCULATED				N
Copano Bay	877 4513 0	36	11/89	5/8/90	Aransas Bay	0.38	0.00	-1.63	0.38	N

(Continued)

Table 5 (Concluded)

Station Name	NOS Station Number	TCOON Number	Installed	Removed	Water Body	mhw ft*	mlw ft*	Observed Lowest ft*	Mn ft	NGVD '29 Tie
F. NOS Chart Numbers 11316 and 11317										
North Matagorda	877 3963 1	23	9/91	--	Espiritu Bay	TO BE CALCULATED				N
Port O'Conner	877 3701 0	57	4/91	4/92	Matagorda Bay	0.81	0.07	-0.84	0.74	N
Rawlings	877 3304	54	6/93	--	Colorado River			--		N
Port Lavaca	877 3259 1	33	9/92	--	Lavaca Bay	0.98	0.10	-0.79	0.88	N
Palacios	877 3156 1	34	9/92	4/95	Matagorda Bay	1.00	0.00	--	1.00	N
G. NOS Chart Numbers 11319, 11321, and 11322										
East Matagorda	877 3001	32	3/92	--	E. Matagorda Bay	0.40	0.00	--	0.40	N
Rivers End	877 2689	49	11/92	--	San Bernard River	0.90	0.10	--	0.80	N
Church Hill Bridge	877 2537	50	11/92	--	San Bernard River	1.10	0.10	--	1.00	N
Freeport Entrance Jetty	877 2479 0	--	10/77	1/80	Gulf of Mexico	1.64	0.38	-1.00	1.26	Y
Freeport	877 2440 1	56	3/95	--	Dow Barge Canal	1.69	0.36	-3.60	1.33	Y
Christmas Bay	877 2132 1	501	10/90	--	Christmas Bay	0.80	0.10	--	0.70	N
Bastrop Bay	877 1984	520	6/95	--	W. Galveston Bay	NOT AVAILABLE				N
H. NOS Chart Numbers 11323, 11326, 11327, and 11328										
Galveston Pleasure Pier	877 1510 1	21	3/91	--	Gulf of Mexico	1.90	0.50	-4.09	1.40	Y
Galveston Pier 21	877 1450 1	22	4/91	--	Galveston Chnl	1.32	0.35	-5.60	0.97	Y
Galveston Bay Entrance	8771416 1	522	11/95	--	Galveston Bay	NOT AVAILABLE				N
Port Bolivar	877 1328 1	521	6/94	--	Galveston Bay	1.30	0.20	--	1.10	N
Eagle Point	877 1013 1	507	4/93	--	Galveston Bay	1.10	0.10	--	1.00	N
Rollover	877 0971	518	6/94	--	East Bay	1.36	0.40	--	0.96	N
Clear Lake	877 0933 1	502	10/90	--	Galveston Bay			--		N
Lynchburg Landing	877 0733 1	517	6/95	--	San Jacinto River	NOT AVAILABLE				N
Morgans Point	877 0613 1	503	5/92	--	Houston Ship Chnl	1.19	0.15	-2.21	1.04	N
Round Point	877 0559	505	9/92	--	Galveston Bay			--		N
I. NOS Chart Numbers 11332 and 11342										
High Island	877 0923	509	4/94	--	Gulf of Mexico	2.10	0.50	--	1.60	N
Sabine Pass	877 0570 1	16	3/90	--						
Mesquite Point	877 0539	506	5/93	--	Sabine Lake	1.20	0.30	--	0.90	N
Port Arthur	877 1238 1	524	--	--						

*Note: mhw, mlw, and Lowest Observed are referenced to local mllw = 0.0 ft.

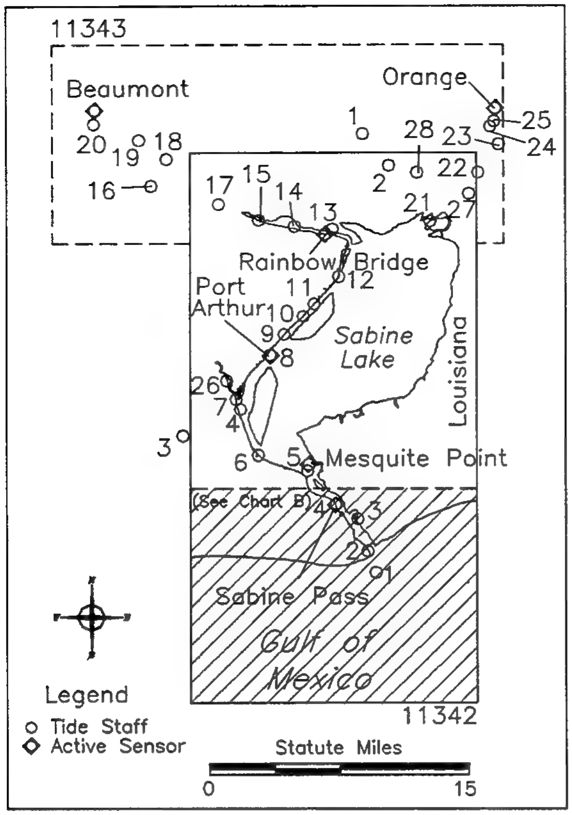

Figure 13. Chart A (Includes NOAA Charts 11342 and 11343)

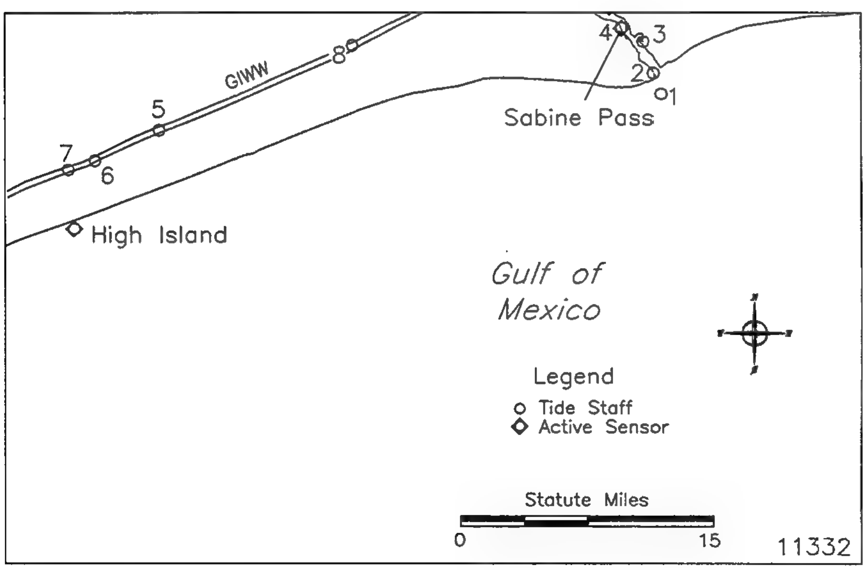

Figure 14. Chart B (Includes NOAA Chart 11332)

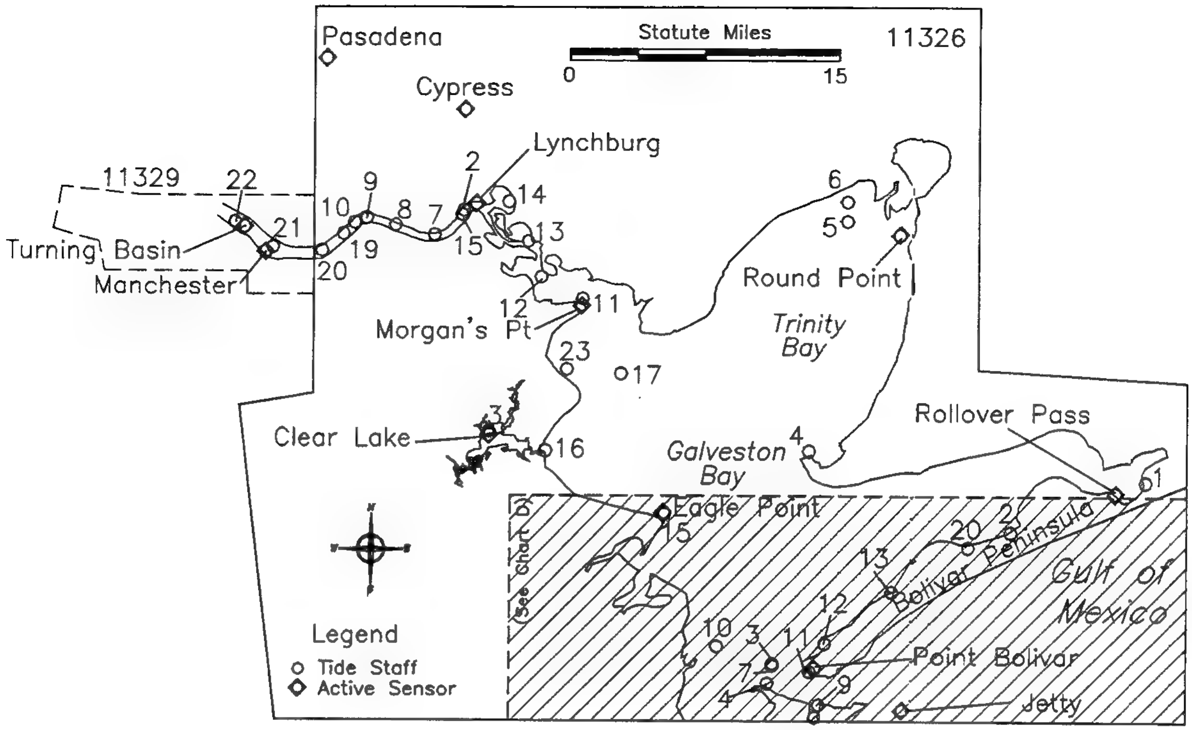

Figure 15. Chart C (Includes NOAA Chart 11326 and 11329)

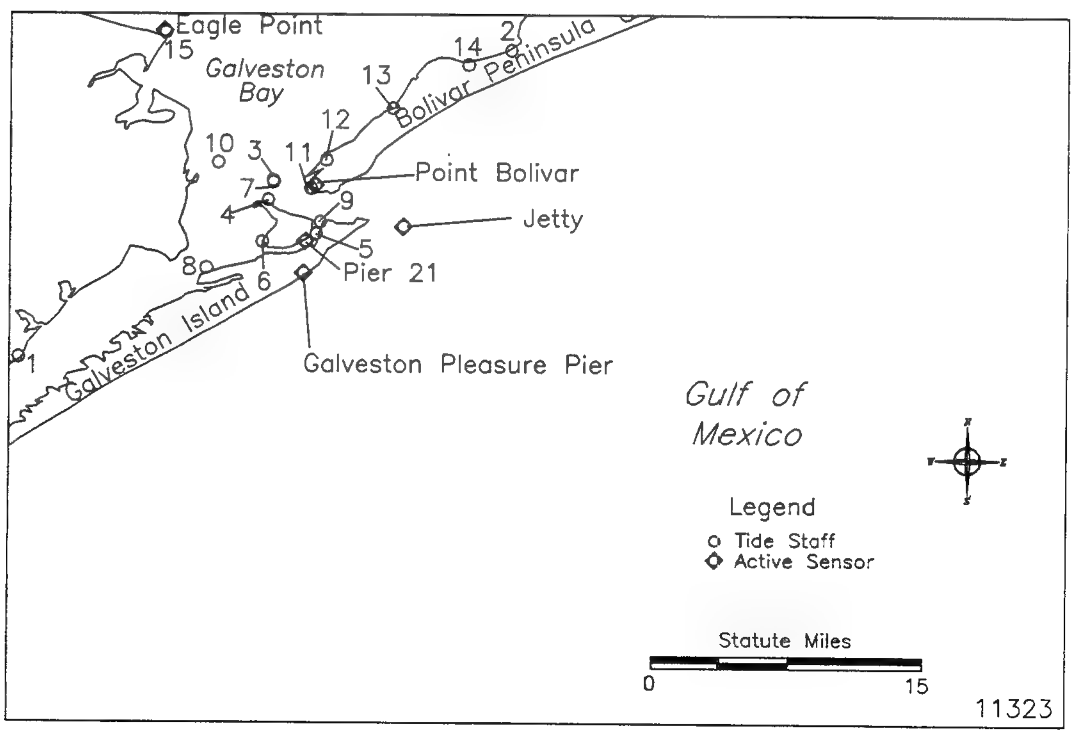

Figure 16. Chart D (Includes NOAA Chart 11323)

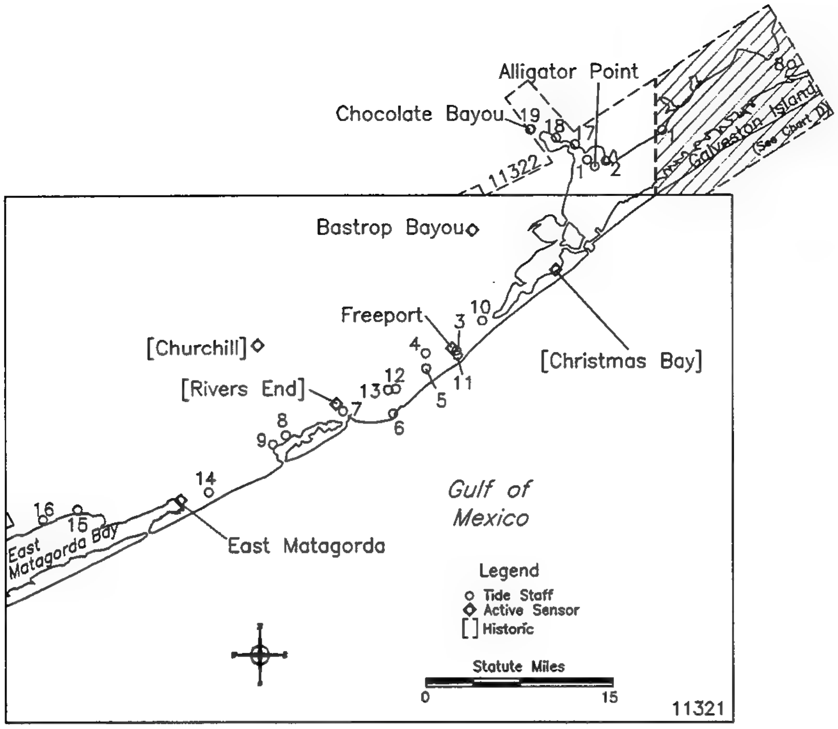

Figure 17. Chart E (Includes NOAA Charts 11321 and 11322)

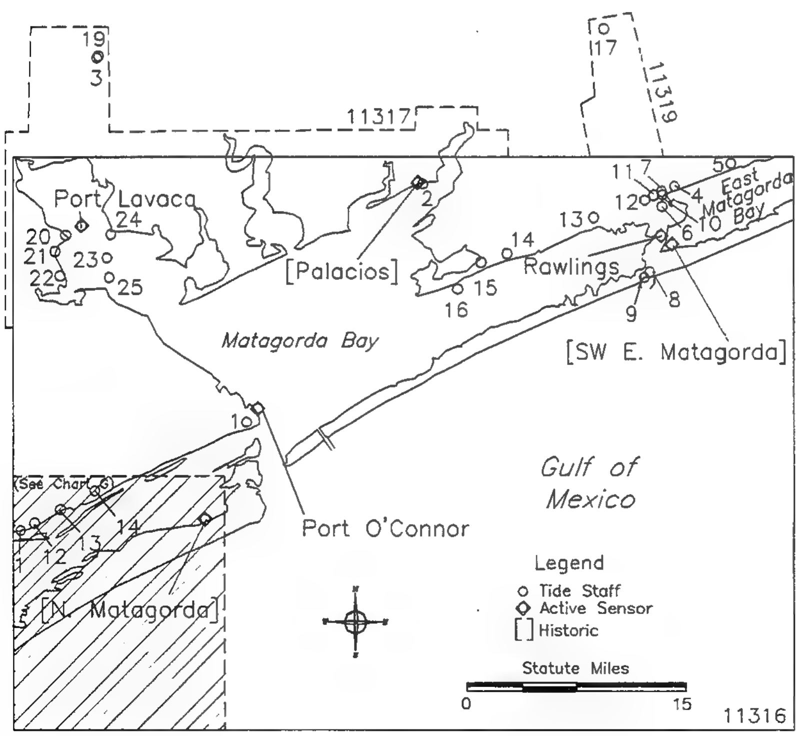

Figure 18. Chart F (Includes NOAA Charts 11316, 11317, and 11319)

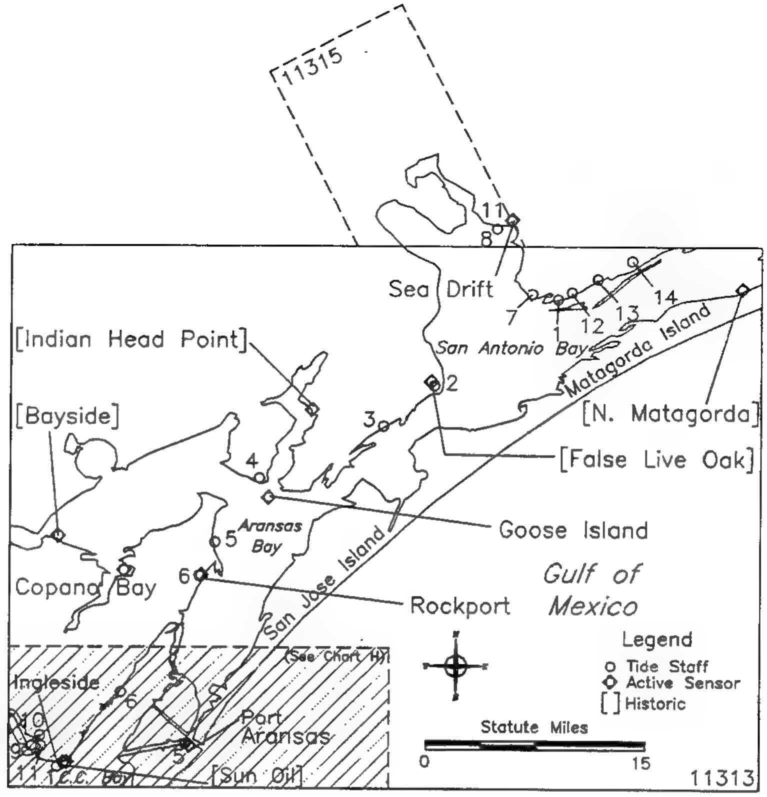

Figure 19. Chart G (Includes NOAA Charts 11313 and 11315)

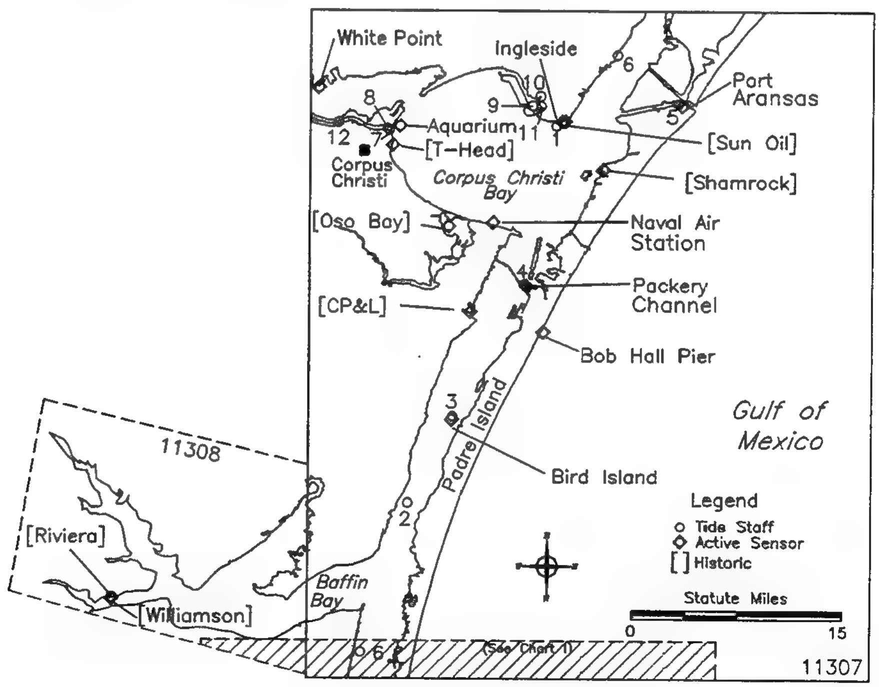

Figure 20. Chart H (Includes NOAA Charts 11307 and 11308)

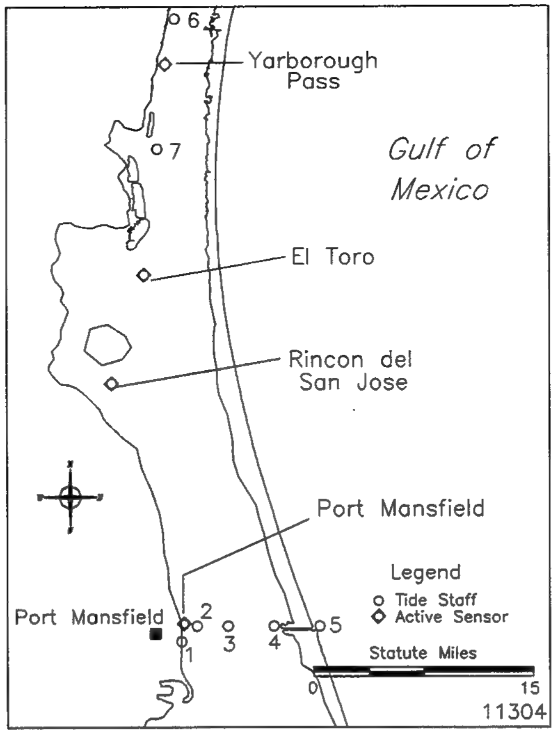

Figure 21. Chart I (Includes NOAA Chart 11304)

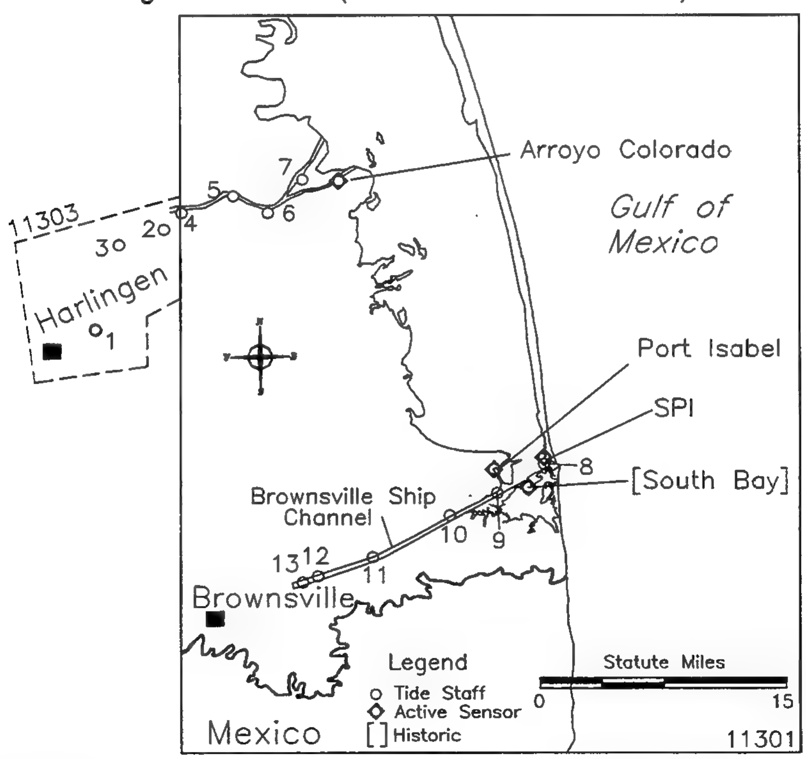

Figure 22. Chart J (Includes NOAA Charts 11301 and 11303)

Example of Need for Gauges

The inland bays and estuaries along the Texas coast are connected to the Gulf of Mexico through narrow and, in some cases, shallow openings in the barrier islands. As the tidal movement from the Gulf progresses through these openings, it is diminished by the restrictions and by friction. The astronomical force becomes weak compared to the strong meteorological forces and is frequently masked and impossible to consistently identify. The masking makes the computation of a tidal datum difficult or impossible in the traditional manner. Kraus and Militello (1996) document wind setup and setdown of water level on the eastern and western ends of East Matagorda Bay, Texas, and found a difference of 2 ft in water level at opposite ends of the bay produced by a winter northern front, with 1-ft differences occurring almost weekly in winter. The tidal range in East Matagorda Bay is only 0.4 ft.

Much of the area within the navigational waterways is nontidal, which has been observed from historic data and existing TCOON stations (Gill, Hubbard, and Dingle 1995). Where tidal datums cannot be determined, stations will need to be spaced to determine and record variability in elevations within each area. An example of such variability is shown in Figure 11, which is a plot of simultaneous records from three stations in the Land Cut in the Laguna Madre. The stations, going from north to south, are Yarborough (004), EL Toro (007), and Rincon de San Jose (003), which are located approximately 15 miles apart.

The horizontal axis plots time and covers a 2-day period. The vertical axis represents the height of the water in feet. The three records are plotted on the individual station datums or zeros, which are arbitrary and have no direct height relationship between stations. The purpose of the graph is to demonstrate how the water level changes between stations within close proximity. The water level can be rising in one area, but falling in another area just a few miles away. The downward pointing spikes in the records are probably associated with the drawdown accompanying the passage of barges. By associated pairs of spikes with the passage of the same barge tow at El Toro and Rincon, the speed of the barges can be estimated.

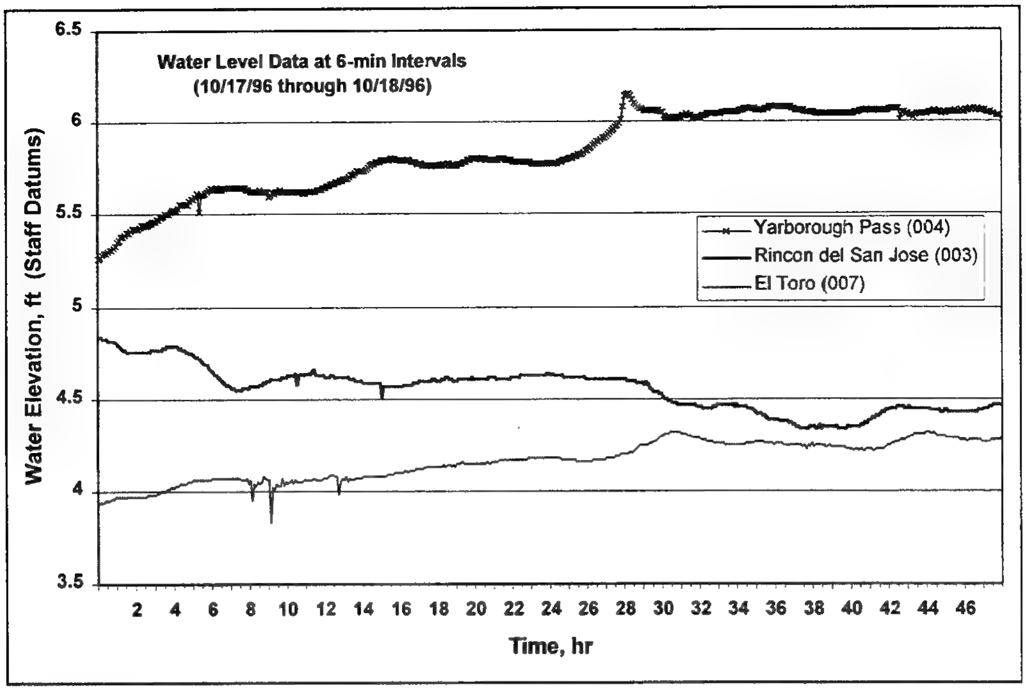

Figure 23. Plot of simultaneous water-level records at three neighboring nontidal stations along the GIWW

Establishment of Stations

Because of the variability in water-level change within short distances along the shallow inland waters of Texas, numerous temporary gauges will be needed for establishing requirements for long-term stations. The next step in designing a network should be a detailed field reconnaissance to determine suitable locations for short-term stations. Such a reconnaissance may take on the order of a month and involve CESWG Area Office personnel, as well as coordination with personnel overseeing dredging operations and regulatory functions.

Short-term stations should be operated for a minimum of 30 days to provide data for zoning the area. The requirement for the number and location of long-term stations for navigation and regulatory support can then be made.

To meet its specific needs during particular dredging operations, the CESWG has in the past made water-level measurements and will continue to do so. It is desirable that these project-level gauges be referenced to benchmarks, and they must be referenced to the applicable NOS chart

datum. The sensors and associated equipment used to make the measurements should meet the accuracy requirements of the USACE for its dredging mission and conform as much as possible to the needs of other agencies. There may well be several methods of acquiring reliable data. We should always be cognizant of new developments in this field. However, before introducing these procedures into the TCOON, reliability and acceptability should be verified.

6 Conclusions and Recommendations

A needs assessment was conducted to determine the requirements of the CESWG, for water-level and associated information along the coast of Texas, focusing on the inland coastal waters. The CESWG will use this information in maintaining Federal navigable waterways, coastal engineering, and environmental regulation in Texas. The assessment included evaluation of the existing Federal and state infrastructures for making water-level and wind measurements along the Texas coast, relevant regulations and practices of the USACE and NOS, typical projects and uses of water-level data by CESWG, and several anticipated future needs of CESWG.

Main requirements of CESWG for water-level information and recommendations are given below. The material is organized according to individual subjects with the requirements and recommendations developed from the information and findings described in the main text and appendices of this report.

Federal and State Cooperation (Backbone Network)

An excellent network of water-level and wind measurement stations exists along the Texas coast that has been primarily supported by the TGLO and the TWDB. It is recommended that the CESWG join these state agencies and other users of the TCOON in supporting and improving the network, and in prioritizing its activities according to common needs. A TCOON Steering Committee, formed of representatives from Federal and state agencies contributing financial support for the network, now

meets periodically throughout the year to review performance and quality of products, set priorities, apportion funds, and plan future work. In formulation of a backbone network with shared resources, priority in allocation of resources is decided by the Steering Committee members to minimize imbalances in benefits.

The backbone network is a collection of stations and capabilities that meets the common needs of all member agencies of the TCOON Steering Committee. Table 6, located at the end of this chapter, gives guidance on those water-level stations recommended for support of CESWG requirements as part of the backbone network. Existing and recommended future stations are listed in the table. Table 6 integrates much of the work conducted in this study.

Real-Time Voice Reporting

Up to 1996, the TCOON had existed primarily to provide information for three purposes. These are: (a) dealing with boundary issues between the state and private-property owners, (b) operating the state's numerical simulation models of water circulation and water quality, and (c) operating the state's soil-spill fate numerical simulation model (presently obtaining wind data in near-real time via the internet). Reporting of water level is of highest priority, followed by provision of wind speed and direction reporting at selected stations.

Past state-related functions of the TCOON have rarely required real-time data voice reporting. However, real-time voice reporting is considered an essential part of a backbone network designed to meet operational needs of CESWG. Real-time reporting will benefit agencies involved with oil-spill prevention and response, as well as Federal, state, and local agencies faced with decisions on hurricane-response evacuation. Other beneficiaries of real-time voice reporting would be the U.S. Coast Guard, waterways transportation industries of various kinds (such as ports and barge operators), environmental interests, and academic research and education programs. A portion of the backbone network funding should, therefore, be identified for staged introduction of real-time reporting according to priorities set by the TCOON Steering Committee.

Voice reporting should satisfy at least five requirements. Information should be: (a) available in near-real time (for example, refresh rate of 15 min); (b) given in engineering units (presently, feet); (c) referenced to chart datum; (d) easily repeated by telephonic or radio command, without having to redial; and (e) obtainable the day after original interrogation for verification and archival in project files.

Voice reporting may be by telephone (land line or cellular) or by radio. However, provision should be made to allow priority access by the TCOON Steering Committee agencies, as distinguished from possible access by other agencies and the general public.

Training of Galveston District Personnel

A training program and materials should be developed for CESWG Area Office and other personnel who will require the real-time and archived data. The training would include such topics as review of tidal datums and relations to District project low-water datums (see next section), review of previous datums used by CESWG and their relation to present-day datums, elements of the forces producing water-level change, properties of water-level change along the coast, practical aspects of communication with the gauges, and use of the WWW with associated data downloading and printing of graphs and tables. Without orientation and special training of its personnel, the CESWG will not obtain maximum benefit from participation in the TCOON.

Project Low-Water Datums

Much of the inland coastal waters of Texas, which are traversed by several hundred miles of maintained navigable channels, experiences water-level variations that are not well quantified by traditional NOS methods of datum determination. Seasonal changes in water level as well as wind setup and setdown can obscure or dominate tidal induced water-level signals. As a result, water level drops considerably below chart datum (mllw, mlw, or msl, depending on the chart) for considerable time (order of several days).

Therefore, for assuring safe navigation, we recommend that the CESWG develop project low-water datums based on water-level observations. The project low-water datums, specific to certain locales depending on the known properties of the water level variation, would be referenced to an existing NOS chart datum, if available. A specialized effort needs to be implemented to develop rational and defensible project low-water datums. That is, project low-water datums should be based on observation and sound procedures, and the determined values should not be unreasonably conservative, thereby causing unnecessary dredging.

Engineering Utility of Archived Data

The existing WWW internet site (http://dco.cbi.tamucc.edu/data) for accessing TCOON data is a sound basic system. Data loaded to the site may be as recent as 3 hr old. Lists of data and plots can be generated by command for arbitrary time intervals, and the queried information can be downloaded.

Presently, the data are reported to the (arbitrary) local staff zero, called the "datum of tabulation." The datum of tabulation remains constant through the life of a station (even if the physical gauge is removed, later to be replaced) and is one of the key procedures in the process of relating water level to fixed benchmarks on land. However, the datum of tabulation is arbitrary and not, of itself, physically meaningful. Two enhancements to the WWW site need to be made for applications of the data by the CESWG and its contractors. These enhancements will also be valuable for any engineering or scientific study or project.

First, the WWW site should provide the relation between staff zero and the mllw datum (or msl if mllw cannot be defined, as in nontidal waters) and an option given to plot the data to mllw or msl. This capability can be added with little effort. Second, all tidal datums available for the individual stations should be accessible. Other datums, such as mhw and msl, enter in regulatory functions and environmental modeling conducted by the CESWG and its contractors. Extreme high- and low-water levels contained in the record, as well as the tidal range, should be given. As much as possible, and in coordination with NOS, the tidal datums should be computed to the most recent 19-year interval if the NTDE is not

updated to modern time. This second capability will require some effort, but could be accomplished within a calendar year.

Project-Specific Operational Gauges

The backbone network, described in Recommendation 1 and in Table 6, is the system of long-term gauges and selected short-term gauges that serve as primary references and furnish continuous records. The backbone network serves the common need of all TCOON Steering Committee member agencies.

The CESWG has its own specific needs for short-term water-level measurement and reporting at the project level. Such a project might have duration on the order of 1 to 6 months. Voice-reporting project-specific gauges would greatly reduce cost and improve reliability in performing reconnaissance surveys, project-condition surveys, contract-payment surveys, and surveys made during the course of dredging in navigable channels and waterways. The minimum number of operational gauges necessary can be determined through the process of reconnaissance and tidal zoning as described in this report. Typically, one to three short-term project gauges might be necessary if gauges from the backbone network augment their capability.

As part of a long-term plan, permanent or semi-permanent platforms or mounting areas must be constructed and maintained. The platforms should be designed such that a permanent vertical elevation can be identified, allowing the water level measured at the project-specific gauges to be tied to the NOS datum applicable to those waters.

Project-specific water-level gauges need not be to the same high accuracy as backbone gauges that have the function of making measurements to determine traditional tidal datums. Backbone gauges employ equipment and procedures to assure overall accuracy on the order of a few millimeters. The function of project-specific gauges is to control soundings taken in maintenance of navigation channels. In project-related hydrographic surveys made in water depths of 10 to 25 ft, for example, sounding equipment and procedures are expected to have total-system accuracy of ± 0.2 to ±0.5 ft (USACE 1991), depending on sea state and

texture of the bottom sediments, among other variables. Therefore, it is appropriate to require project-specific water-level gauges to be accurate to ± 0.1 to ± 0.2 ft, depending on environmental conditions at the site and distance to the nearest backbone gauge. Such accuracy may be economically achievable with DGPS technology, but this technology must be tested.

In addition to documented and verifiable surveying procedures, calibration records on the water-level instruments or sensors should be kept. It is recommended that, for Texas inland coastal waters, self-contained pressure gauges with radio transmission capability be investigated for fulfilling requirements of project-specific operational water-level gauges.

Data stored in or transmitted from the project gauges should be compatible with TCOON standards, for example, as an average taken over a 6-min interval. The data should be incorporated in the TCOON database, together with the associated local reference elevation of the platform and other essential information that will allow re-establishment of the "project station" and access by interested parties. If measurements made to meet project-level requirements have greater tolerances or reliability than backbone gauges, the accuracy range of the values in the database should be provided as part of the information given with the raw or processed data.

Outside (Gulf-side) Gauges and Wave Measurement

The capabilities of dredging and navigating in a channel or waterway depend on sea state (surface wave height, period, and direction), as well as on absolute water depth. Measurement of sea state is particularly pertinent in entrance channels and in the offshore of deep-draft channels. Individual surface waves (typical periods of 5 to 10 sec) as well as longer period swell (typical period of 30 to 60 sec) can disrupt or halt dredging operations and make navigation unsafe. Real-time voice reporting and documentation of sea state could be incorporated into dredging operations to make them more efficient, as well as make navigation safer.

Wave height and period can be measured with pressure gauges. Such gauges can also report water-level variations. Vertical and horizontal position of the gauges may be determined for support of dredging operations with sufficient accuracy through DGPS survey.

Investigation of DGPS

Many of the inland coastal waters of Texas are nontidal according to traditional NOS determinations. Therefore, a reference for navigational purposes other than mllw must be used. Because interconnection of the stations through conventional differential levels is not feasible, surveying by vertical as well as horizontal DGPS procedures should be considered, with due regard to verification of stated accuracy.

Table 6
Recommended Long-Term Water-Level Stations (Backbone Network) and Required Short-Term Stations to Fill in Gaps for Support of USACE Operations

Station Name	NOS Station No. 877-	Comments
NOS Chart Numbers 11332, 11342 Sabine Pass, Sabine Lake, Port Arthur		
Sabine Pass	0570 1	NOS long-term station
Mesquite Point	0539	Uncertain if this station is necessary – needs detailed evaluation
High Island	0923	Low waters being cut off; gauge must be moved
Port Arthur	1238 1	
NOS Chart Numbers 11323, 11326, 11327, 11328 Galveston Entrance, Galveston Bay, Houston Ship Channel		
Rollover	0971	
Galveston Pleasure Pier	1510 1	NOS long-term, open-Gulf station
Galveston Pier 21	1450 1	NOS long-term station
Galveston Bay Entrance	1416 1	
Point Bolivar	1328 1	
Eagle Point	1013 1	
Clear Lake	0933 1	Uncertain if this station is necessary – needs detailed evaluation
Lynchburg Landing	0733 1	
Morgan's Point	0613 1	
Round Point	0559	
NOS Chart Numbers 11316, 11319, 11321, 11322 Freeport, East Matagorda Bay, Colorado River		
Freeport	2440 1	NOS long-term station
East Matagorda	3001 1	
Colorado River Locks		Recommended placing long-term gauge at confluence of GIWW and Colorado River
NOS Chart Numbers 11316, 11317 Colorado River Navigation Channel, Matagorda Bay, Espiritu Santo Bay		
Rawlings	3304	Overlap record with a new Colorado R. Navigation Channel Entrance Station, then remove
Mouth of Colorado River Navigation Channel		If maintenance of the CR Navigation Channel will continue, then recommend installation of open-Gulf station on the north jetty and removal of Rawlings
Entrance of GIWW land cut to Matagorda Bay		Establish short-term station to determine tidal characteristics in central portion of bay and compare to Port O'Conner and Port Lavaca stations
Matagorda Ship Channel short- or long-term station		Establish station on bay side of the ship channel and compare to Port O'Conner to determine differences; if similar characteristics, remove Matagorda Ship Channel gauge and retain Port O'Conner gauge
Port Lavaca	3259 1	
Port O'Conner	3701 0	
Espiritu Santo Bay short-term station		Establish short-term station to determine tidal characteristics between Port O'Conner and San Antonio Bay
Victoria Barge Canal long-term station		Establish station reporting water level and wind

(Continued)

Table 6 (Concluded)		
Station Name	NOS Station No. 877-	Comments
NOS Chart Numbers 11313, 11314 San Antonio Bay, Aransas Bay		
San Antonio Bay – Short-term or long-term station		Establish station in San Antonio and determine whether it should be long-term based on tidal characteristics and dredging operation needs
Copano Bay	4513 0	
Rockport	4770 1	NOS long-term station
NOS Chart Numbers 11308, 11309 Corpus Christi Bay, Corpus Christi Ship Channel		
Port Aransas	5237 1	Adjacent to Corpus Christi Ship Channel
Port Ingleside	5283 1	Not strictly necessary, but has solid infrastructure; also, is near intersection of GIWW and CC Ship Channel
Texas State Aquarium	5296 1	Near the Corpus Christi harbor entrance
CC Naval Air Station	5421 1	Test station for TCOON
Packery Channel	5792 1	
NOS Chart Number 11307 Corpus Christi Bay, Upper Laguna Madre, Baffin Bay		
Corpus Christi, Bob Hall Pier	5870 1	NOS long-term open-Gulf station
South Bird Island	6139 1	Marginally tidal
Short-term stations		Establish two or three short-term stations between South Bird Island (marginally tidal) and Yarborough Pass (Baffin Bay) (nontidal) to determine tidal characteristics along the GIWW
NOS Chart Numbers 11304, 11306, 11308 GIWW Land Cut, Port Mansfield		
Yarborough Pass	6687 1	Nontidal
El Toro	7562 1	Nontidal
Rincon del San Jose	7812 1	Nontidal
Short-term stations		Establish one or two short-term stations between Rincon and Port Mansfield stations to determine tidal characteristics between the two locations
Port Mansfield	8490 1	NOS long-term station; nontidal
NOS Chart Number 11301 Arroyo Colorado, Lower Laguna Madre, Brownsville Ship Channel, Port Isabel		
Arroyo Colorado	9038	Nontidal
Short-term stations		Establish two or three short-term stations between Arroyo Colorado (nontidal) and the Port Isabel & SPI-CG (tidal) stations to determine tidal characteristics along the GIWW
Port Isabel	9770 1	Long-term NOS gauge
South Padre Island, Coast Guard Station	9748 1	Near Brazos Santiago Ship Channel and jetties
Long-term open Gulf station		If Cameron County rebuilds a fishing pier at South Padre Island, re-establish a long-term Gulf station for dredging operations at Brazos Santiago Entrance Channel

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Appendix A
Locations and Capabilities of TCOON Stations, September 1996

Table A1
TCOON and NOS Water-Level Stations

Station Name	TCOON Station	NOS Station	Lat. / Long.	Start of Record	End of Record	Other Sensors	Backup
Alligator Point	508	87718011	29 10.0' 95 07.5'	Oct 92	--		
Aquarium	8	CBI90008	27 40.8' 97 23.5'	Apr 90	--	Wind, BP, Air/Water Temp	
Arroyo Colorado	47	87790381	26 21.2' 97 19.5'	Nov 92	--	Wind	
Bastrop Bayou	520	87719841	29 05.4' 95 16.9'	Jun 95	--		
Bayside	30	87746521	28 04.0' 97 12.2'	Feb 93	Dec 95		
Beaumont	514	87705951	30 05.7' 94 05.4'	Sep 94	--		
Bird Island Basin	13	87761391	27 29.1' 97 19.1'	Sep 91	--	Wind, Water Temp	
Bob Hall	14	87758701	27 34.9' 97 13.0'		--		Y
Byarea Park	510	87708111	Not Available	None	--		
Chocolate Bayou	519	87717081	29 12.7' 95 12.4'	None	--		
Christmas Bay	501	87721321	29 02.5' 95 10.5'	Oct 90	Aug 95		
Churchill	50	87725371	28 57.0' 95 33.3'	Nov 92	Jul 94		
Clear Lake	502	87709331	29 33.8' 95 04.0'	Jun 94	--		
Colorado River	48		Not Available	Nov 92	Nov 92		
Copano	36	87745131	28 46.5' 97 31.9'	Jun 92	--		
CP&L B. Davis	20	87758331	27 36.2' 97 18.0'	May 90	Nov 91		
Cypress	516	87706531	29 50.8' 95 05.3'	None	--		
Delta Rincon	29	87752751	Not Available	Nov 91	Jul 93		
Eagle Point	507	87710131	29 29.9' 94 54.7'	Apr 93	--		
East Matagorda	32	87730011	28 45.7' 95 39.2'	Mar 92	--	Wind	
El Toro	7	87752371	26 56.5' 97 27.4'	Mar 90	--	Wind	Y
False Live Oak	38	87742301	28 13.9' 96 47.9'	Jun 92	Apr 94		
Freeport	56	87724401	28 56.8' 95 18.5'		--	Wind	Y
Galv. Pl. Pier	21	87715101	29 17.1' 94 47.3'	Dec 91	--		
Galv. Offshore	525	87719041	29 08.0' 94 28.0'	None	--		
Goose Island	35	87745221	28 20.0' 96 27.1'	Jun 92	--	Wind	

(Sheet 1 of 3)

Table A1 (Continued)

Station Name	TCOON Station	NOS Station	Lat./Long	Start of Record	End of Record	Other Sensors	Backup
High Island	509	87709321	29 32.3' 94 23.1'	Apr 94	--		
Indian Head Pt.	37	87745271	28 12.1' 96 55.7'	Nov 92	Feb 95		
Ingleside	6	87752831	27 49.3' 97 12.2'	Jan 89	--	Wind	
Jetty	522	87714161	29 19.6' 94 42.5'	Nov 95	--		
Lynchburg	517	87707331	29 45.9' 95 04.7'	Jun 95	--		
Manchester	513	87707771	29 43.4' 95 15.9'	None	--		
Mesquite Point	506	87705391	29 46.0' 93 53.7'	May 93	--		
Morgan's Point	503	87806131	29 40.6' 94 59.1	May 92	--		
NASCC	1	87754211	27 42.3' 97 16.8'	May 89	--	Wind	
North Matagorda	23	87739631	28 20.0' 96 27.7'	Feb 91	Jan 96	Wind	
Orange	515	87705971	30 05.8' 93 43.4'	Aug 94	--		
Packery Chnl.	5	87757921	27 38.0' 97 14.2	Nov 88	--		
Palacios	34	87731561	28 41.8' 96 13.9'	Apr 92	Apr 95		
Pasadena	512	87707751	29 53.5' 95 12.7'	None	--		
Pier 21	22	87714501	29 18.8' 94 47.2'	Apr 92	--		
Point Bolivar	521	87713281	29 21.8' 94 46.7'	Jun 94	--		
Port Aransas	9	87752371	27 50.4 97 04.4	May 90	--	Wind	
Port Arthur	524	87704751	29 52.0' 93 55.8'	None	--		
Port Bolivar	521	87713281	29 21.8' 94 46.7'	May 94	--		
Port Isabel	18	87797701	26 03.7' 97 12.9'		--		Y
Port Lavaca	33	87732591	28 38.4' 96 36.6'	Mar 92	--	Wind	
Port Mansfield	47	87790381	26 21.1' 97 19.5'		--		Y
Port O'Connor	57	87737011	28 27.2' 96 24.3'	Jun 95	--		
Rainbow Bridge	504	87705201	29 58.8' 93 52.8'	Sep 93	--		
Rawlings	54	87733041	28 37.7' 95 58.3'	Jun 93	--		
Rincon	3	87790381	26 48.1' 97 28.2'	Mar 90	--	Wind, Water Temp	Y
Rivers End	49	87726891	28 52.7' 95 27.3'	Nov 92	Jul 94		

(Sheet 2 of 3)

Table A1 (Concluded)

Station Name	TCOON Station	NOS Station	Lat./Lang.	Start of Record	End of Record	Other Sensors	Backup
Riviera	10	87766391	27 16.5' 97 42.5'	Mar 92	Feb 95		
Rockport	15	87747701	28 01.5' 97 02.9'		--		Y
Rollover Pass	518	87709711	29 30.9' 94 30.8'	Jun 94	--		
Round Point	505	87705591	29 44.3' 94 42.4'	Sep 92	--		
Sabine Offshore	523	87710811	29 29.9' 93 38.4'	None	--		
Sabine Pass	16	87705701	29 43.8' 93 52.2'	Aug 90	--		
Seadrift	31	87730371	28 24.4' 96 42.7'	Feb 92	Jul 93		
Shamrock Island	39	87754221	27 45.9' 97 09.0'	Mar 92	Jan 95		
SPI/Pt. Nowell	51	87797481	26 04.4' 97 10.0'	Apr 93	--	Wind	
T-Head	2	87753511	27 47.7' 97 23.3	Feb 90	Apr 96	Wind, Air Temp, BP	
Turning Basin	511	87705551	29 44.7' 95 17.0'	None	--		
White Point	11	87751881	27 51.6' 97 29.0'	Jul 90	--	Wind	
Yarborough	4	87766871	27 10.0' 97 26.4'	Feb 90	--	Wind, Water Temp	Y

(Sheet 3 of 3)

Appendix B
Locations of Galveston District Tide Staffs, September 1996

Table B1
Locations of USACE – Galveston District Tide Staffs

Waterway	Map Key	Location	Lat/Long	MLT Ft Below NGVD	Comments
Chart A (Includes NOAA Charts 11342 and 11343)					
Cow Bayou	A1	Staff on timber bridge	30° 04' 23.15" 93° 50' 42.44"		(Small bridge - not used for automobile traffic)
Cow Bayou	A2	Bridge City Bridge	30° 02' 38.37" 93° 49' 15.96"	N/A	Staff on timber bulkhead near Moore's Landing
GIWW	A3	Near destroyed salt water barrier	29° 47' 35.45" 94° 00' 36.19"	N/A	Staff on timber pile along south bank
Sabine-Neches WW	A4	Staff on red day marker 48	29° 49' 2.2" 93° 57' 27.7"	N/A	Staff west of Bethlehem Ship Yard just south of GIWW
Pt. Arthur Ship Channel	A5	Hwy 82 bridge	29° 45' 38.5" 93° 53' 47.1"	N/A	Staff on red day marker 40 near causeway bait shop
Pt. Arthur Ship Channel	A6	Keith Lake bridge	29° 46' 31.0" 93° 56' 28.6"	N/A	Staff on green day marker 43
Pt. Arthur Ship Channel	A7	GIWW / Pt. Arthur Channel	29° 49' 34.5" 93° 57' 42.2"	N/A	Staff near West Port Arthur Bridge on range marker
Sabine-Neches WW	A8	COE Office at U.S. Coast Guard dock	29° 52' 1.8" 93° 55' 48.6"	N/A	Staff on bulkhead
Sabine-Neches WW	A9	North bank at pump station	29° 53' 10.61" 93° 55' 3.20"	N/A	Staff on pile
Sabine-Neches WW	A10	North bank at pump station	29° 54' 11.28" 93° 54' 0.63"	N/A	Staff on pile
Sabine-Neches WW	A11	North bank at pump station	29° 54' 52.88" 93° 53' 23.87"	N/A	Staff on pile
Sabine-Neches WW	A12	At Sabine Towing dock	29° 56' 25.23" 93° 52' 2.84"	N/A	Staff on timber bulkhead at north bank
Neches River	A13	Under Veterans Memorial Bridge	29° 59' 4.48" 93° 52' 23.62"	N/A	Staff on caisson at north bank of river
Neches River	A14	Near Deer Bayou	29° 59' 15" 93° 54' 29"	N/A	
Neches River	A15	Near Port Neches at Star Enterprise docks	29° 59' 34.66" 93° 56' 27.16"	N/A	Staff on pile cluster 20 ft from north bank
Neches River	A16	Beaumont Maritime Reserve dock	30° 01' 31.16" 94° 02' 19.46"	N/A	Staff on timber bulkhead
Neches River	A17	Near Sun Oil pump station	30° 00' 29.17" 93° 58' 39.8"	N/A	Staff on pile cluster 20 ft from north bank
Neches River	A18	Beacon #56	** 30° 03' 00" 94° 01' 30"	N/A	(Did not find staff during survey)
Neches River	A19	Near Star Bayou	30° 04' 02.56" 94° 02' 59.52"	N/A	Staff on timber bulkhead at Gulf Space Utilities Camp
Neches River	A20	At railroad bridge near River Front Park	30° 04' 55.22" 94° 05' 27.57"	N/A	Staff on timber pile cluster 50 yd from shore
Sabine Lake	A21	West Pass	29° 59' 31.85" 93° 47' 00.54"	N/A	Staff on range marker about 40 ft from shore

(Sheet 1 of 8)

Notes: NGVD relationships from table provided by Lynwood Weiss, USACE, Galveston District, dated March 22, 1990.
NOS Standard Chart numbers used.
** Estimated from chart.

Table B1 (Continued)					
Waterway	Map Key	Location	Lat/Long	MLT Ft Below NGVD	Comments
Chart A (Includes NOAA Charts 11342 and 11343) (Continued)					
Sabine River	A22	Sabine Pipeline	30° 02' 14.89" 93° 44' 21.51"	N/A	Staff on timber bulkhead
Sabine River	A23	Port of Orange	30° 03' 48.74" 93° 43' 12.69"	N/A	East of Adams Bayou; staff on small wooden pier
Sabine River	A24	Near Orange Harbor	30° 04' 46.88" 93° 43' 41.02"	N/A	Staff on timber bulkhead at shipyard
Sabine River	A25	Near Phoenix Lake	30° 05' 04.52" 93° 43' 27.83"	N/A	Staff on timber bulkhead near American Bridge shipyard rear dock
Taylor Bayou Turning Basin	A26	Near intersection of GIWW and Port Arthur Ship Canal	29° 50' 36.8" 93° 58' 13.0"	N/A	Staff on shrimp boat timber dock
Sabine River	A27	North of Black Bayou	30° 01' 04.72" 93° 44' 51.37"	N/A	Staff on red day marker 8
Cow Bayou	A28	West of Sabine River at Round Bunch Bridge	30° 02' 14.42" 93° 47' 42.80"	N/A	Staff on cluster of mooring piles
Chart B (Includes NOAA Chart 11332)					
Jetty Channel	B1	W. front range light	** 29 44 93 40	N/A	(Staff not visited during survey)
Jetty Channel	B2	Pilot Station at Texas Point	29° 41' 11.69" 93° 50' 26.16"	N/A	Staff on pilot boat dock
Sabine Pass Channel	B3	Old Coast Guard Station	** 29° 43' 93° 51'	N/A	(Staff not visited during survey)
Sabine Pass Channel	B4	U.S. Coast Guard	29° 43' 46.33" 93° 52' 14.62"	N/A	Staff on timber dock
GIWW	B5	NE of marker 315 at Barnes Slough	29° 37' 56.70" 94° 18' 18.00"	N/A	Staff at abandoned house on south bank of GIWW
GIWW	B6	Near High Island	29° 36' 12.20" 94° 21' 55.12"	N/A	GIWW-south bank / State Hwy 124, AT&SF Railway bridge (destroyed); staff on timber pile
GIWW	B7	At State Hwy. 124	29° 35' 41.24" 94° 23' 25.26"	N/A	Staff on small pier about 200 yd from bridge
GIWW	B8	NW of Clam Lake	29° 42' 46.64" 94° 07' 27.26"	N/A	Staff on timber bulkhead at south bank (Sonat Exploration Company)
Chart C (Includes NOAA Charts 11326 and 11329)					
GIWW – Gilchrist	C1	Off Faggard's Slip Road	29° 31' 27.8" 94° 29' 11.7"	N/A	At Rollover Pass; staff on south bank of GIWW
Houston Ship Channel	C2	Near Battleship Texas	29° 45' 20.63" 95° 05' 27.05"	N/A	Staff on bulkhead at park
Clear Lake	C3	Near Ramp	** 29° 34' 95° 04'	N/A	(Staff not visited during survey)
Trinity River	C4	Trinity River Channel	** 29° 33' 94° 47'	N/A	At Smith Point near ramp
GIWW	C5	Junction Canoe Creek	** 29° 45' 95° 45'	N/A	Near Live Oak Bay & Boggy Bayou, south of Sargent
Trinity River	C6	Trinity River Channel	** 29° 46' 94° 45'	1.00	Near State Hwy 562 & Sykes Rd.; Round Point, north of Ash Point, near channel to Liberty
					(Sheet 2 of 8)

Table B1 (Continued)					
Waterway	**Map Key**	**Location**	**Lat/Long**	**MLT Ft Below NGVD**	**Comments**
Chart C (Includes NOAA Charts 11326 and 11329) (Continued)					
Houston Ship Channel	C7	At green channel marker 139	29° 44' 17.03" 95° 06' 55.49"	N/A	
Houston Ship Channel	C8	South bank of channel under Beltway 8 toll bridge	29° 44' 48.11" 95° 08' 59.73"	N/A	
Houston Ship Channel	C9	Near Green's Bayou and Todd's Ship Yard	29° 45' 11.0" 95° 10' 31.4"	N/A	
Houston Ship Channel	C10	At Tessondlo Kerley plant	29° 44' 55.54" 95° 11' 08.80"	N/A	
Houston Ship Channel	C11	At Morgan's Point	29° 40' 56.7" 94° 59' 02.7"	N/A	Near Barbour's Cut
Houston Ship Channel	C12	Near Spilmans Isl. on range marker	29° 42' 5.0" 95° 01' 14.7"	N/A	Also near HWY 146
Houston Ship Channel	C13	Near Alexander Island	29° 43' 57.6" 95° 01' 56.9"	N/A	At Scott Bay; staff on rear range platform
Houston Ship Channel	C14	Near Lynchburg Ferry	** 29° 46' 95° 03'	N/A	Electronic tide gauge at this station
Houston Ship Channel	C15	Near Battleship Texas Monument	29° 45' 33.22" 95° 05' 21.97"	N/A	Near green channel marker 151
Clear Creek Channel	C16	Galveston Bay/Clear Creek	** 29° 33' 95° 01'	N/A	(Staff not visited during survey)
Bayport Ship Channel	C17	Bayport/Houston Channel junction	** 29° 37' 95° 01'	N/A	(Staff not visited during survey)
GIWW - High Island	C18	Approx. station 1800+00 in GIWW	N/A	N/A	Staff on navigation range 11
Houston Ship Channel	C19	At Mobile Mining Plant near Hunting Bayou	29° 44' 19.8" 95° 11' 44.76"	N/A	
Houston Ship Channel	C20	At San Jacinto Mill above Washburn Tunnel	29° 43' 27.02" 95° 12' 54.20"	N/A	Staff on green marker 163
Houston Ship Channel	C21	At U.S. Coast Guard Station	29° 43' 27.02" 95° 12' 54.20"	N/A	Near Loop 610 bridge
Houston Ship Channel	C22	Turning Basin	29° 44' 57.4" 95° 17' 27.1"	1.14	
Houston Ship Channel	C23	Bayport at Houston Yacht Club	29° 37' 13.8" 94° 59' 52.5"	N/A	Off Shoreacres Road
Chart D (Includes NOAA Chart 11323)					
GIWW - West Bay	D1	Near Caranchua Point	29° 12' 37.90" 95° 02' 22.71"	1.41	Approx. 6 to 7 mi. east of Chocolate Bay; about 1000 ft east of marker 370
GIWW - High Island	D2	At Stingaree Restaurant	29° 28' 54" 94° 36' 19"	N/A	South bank of GIWW near Stingaree Road
Texas City SC	D3	End of Texas City Dike	29° 22' 02.00" 94° 48' 54.73"	1.41	Staff on north side of dike about 20 ft from dike
GIWW Main Chnl.	D4	Through Pelican Isl. (at Pelican Spit)	29° 20' 59.6" 94° 49' 09.9"	N/A	Staff near north bank
Galveston SC	D5	Galveston Yacht Basin	29° 19' 12.07" 94° 46' 38.29"	1.41	
Galveston SC	D6	At Pelican Isl. Causeway	29° 18' 45.06" 94° 49' 28.91"	1.41	Staff on timber pile cluster on south side of causeway
Texas City SC	D7	Range Platform at end of Texas City Dike	29° 21' 55.42" 94° 48' 53.24"	1.41	Staff on south side of (about 40 ft from) dike
					(Sheet 3 of 8)

Table B1 (Continued)					
Waterway	Map Key	Location	Lat/Long	MLT Ft Below NGVD	Comments
Chart D (Includes NOAA Chart 11323) (Continued)					
GIWW - W. Galveston Bay	D8	Causeway Fish Camp near HWY 45	29° 17' 21.6" 94° 52' 26.8"	1.41	Near Offatts Bayou
Galveston SC	D9	USACE boat basin	29° 19' 50.61" 94° 46' 25.36"	1.41	Staff on timber pile
Texas City SC	D10	At Texas City Dike (south side)	29° 22' 58.1" 94° 51' 50.5"	1.41	Staff at 1st ramp (from mainland) on south side of dike
Houston SC	D11	Eastern terminus of Bolivar Peninsula (at ferry landing)	29° 21' 37" 94° 46' 56"	1.41	Damaged staff - does not match elevation reading at nearest staff
GIWW – Bolivar Peninsula	D12	Near Stn 3130+00 at Shirley's Bait Camp	29° 25' 51.0" 94° 42' 35.0"	1.41	This staff replaced the staff at 23rd Canal
GIWW – Bolivar Peninsula	D13	At Seiver's Cove (yacht basin) near Stn 2878+00	29° 25' 51.0" 94° 42' 35.0"	1.41	At Shirley's Blue Beacon Bait Camp
GIWW – Bolivar Peninsula	D14	West Canal Road near Stn 2622+00	29° 28' 07.7" 94° 38' 34.6"	1.41	Tide staff has been missing for approx. past year
Houston SC	D15	Eagle Point Marina at Bacliff	29° 29' 47.7" 94° 54' 39.0"	N/A	Staff at East Bay shore
Chart E (Includes NOAA Charts 11321 and 11322)					
Chocolate Bay	E1	Staff on range marker	29° 10' 28.43" 95° 08' 5.85"	N/A	
GIWW – Chocolate Bayou	E2	Near Alligator Point	29° 10' 20.03" 95° 06' 38.76"	N/A	East of marker 375 at green day marker 1; south bank of GIWW
Freeport Entrance Channel	E3	North bank of Surfside Coast Guard Station	28° 56' 37.06" 95° 18' 08.95"	N/A	Staff on concrete bulkhead
Freeport Harbor	E4	Turning basin	28° 56' 25.15" 95° 20' 30.32"	1.43	(Staff missing at time of survey)
GIWW	E5	At Quintana swing bridge	28° 55' 17.68" 95° 20' 28.88"	N/A	
Brazos River	E6	Brazos River entrance	** 28° 52' 95° 27'	1.43	(Staff not visited during survey)
GIWW - San Bernard River	E7	San Bernard River crossing at GIWW	28° 52' 11.74" 95° 26' 47.47"	1.43	North bank of GIWW; staff on abandoned boat dock at old bait camp
GIWW - Cedar Lakes	E8	North of Sargent Beach	28° 50' 26.71" 95° 31' 09.28"	N/A	On north bank of GIWW at mi. marker 410 (staff on pile)
GIWW - Cedar Lakes	E9	North of Sargent Beach	28° 49' 45.52" 95° 32' 07.48"	N/A	(Staff missing at time of survey); will be mounted on a 2 x 8 in board near north bank
GIWW – Surfside	E10	Public boat ramp #16 at surfside	28° 58' 49.47" 95° 16' 09.68"	N/A	Staff near Bay Avenue between 390 & 400 mi. marker
GIWW – Surfside	N/A	Near E10	—	N/A	(Staff not visited during survey)
					(Sheet 4 of 8)

Table B1 (Continued)					
Waterway	Map Key	Location	Lat/Long	MLT Ft Below NGVD	Comments
Chart E (Includes NOAA Charts 11321 and 11322) (Continued)					
Freeport Entrance Channel	E11	Landward end of south jetty	28° 56' 15.97" 95° 18' 03.46"	N/A	Staff on timber pile at dock
GIWW – Brazos River	E12	Brazos River floodgates, east side	28° 53' 47.59" 95° 22' 48.78"	N/A	At USACE boathouse, approx. Stn 241+600, GIWW north bank
GIWW – Brazos River	E13	Brazos River flood-gates, west side	28° 53' 43.80" 95° 23' 22.66"	N/A	On north bank of GIWW
GIWW – Sargent	E14	Sargent swing bridge	28° 46' 17.15" 95° 37' 01.73"	N/A	8-ft wooden staff on pile cluster at end of short pier
GIWW - Live Oak Bayou	E15	Near town of Chinquein	28° 45' 00.78" 95° 46' 59.84"	N/A	East bank of Live Oak Bayou
GIWW - Big Boggy Bayou	E16	North bank of Big Boggy Bayou	28° 44' 17.00" 95° 49' 37.89"	N/A	Staff in board pounded into channel bottom about 40 ft from north bank
Chocolate Bayou	E17	Near Grassy Point on abandoned Coast Guard range	29° 11' 35.3" 95° 09' 00.8"	1.37	Across from red channel marker 20
Chocolate Bayou	E18	On abandoned Coast Guard range	29° 12' 05.3" 95° 10' 28.2"	1.37	Near red day marker 34
Chocolate Bayou	E19	Under 2004 Bridge	29° 12' 41.1" 95° 12' 28.1"	1.37	Staff on west bank on boat ramp bulkhead
Chart F (Includes NOAA Charts 11316, 11317, and 11319)					
GIWW - Port O'Conner	F1	U.S. Parks and Wildlife Office	28° 26' 17.4" 96° 25' 01.6"	N/A	Staff on concrete bulkhead
Channel to Palacios	F2	Near Palacios Harbor	28° 41' 41.35" 96° 13' 34.42"	N/A	Staff on survey table
Channel to Red Bluff	F3	At railroad bridge near Hwy 616 bridge	28° 49' 53.95" 96° 34' 41.23"	N/A	(Staff missing at time of survey)
GIWW – Matagorda	F4	1000 ft east of Matagorda Harbor entrance	28° 41' 33.40" 95° 57' 06.49"	N/A	East of 440 mi. marker; staff on mooring pile cluster
GIWW	F5	At Old Gulf Plant	28° 43' 00.98" 95° 53' 23.75"	N/A	North bank of GIWW on damaged timber dock
GIWW – Colorado River	F6	Matagorda swing bridge	28° 41' 13.12" 95° 53' 23.75"	N/A	Staff on timber platform 1,000 ft east of highway
GIWW – Colorado River	F7	Colorado River locks; west of swing bridge in USACE boat house	28° 41' 13.3" 95° 57' 56.6"	1.43	Staff on timber bulkhead
Colorado River Entrance Channel	F8	1500 ft inland from mouth of Colorado River	28° 36' 02.08" 95° 58' 43.41"	N/A	Staff on timber pile on east shore of channel
Colorado River Entrance Channel	F9	Mouth of Colorado River - west bank	28° 35' 41" 95° 59' 05"	N/A	Staff on day marker 3
Colorado River Entrance Channel	F10	River Bend Boat Camp	28° 40' 14.71" 95° 57' 55.57"	N/A	Staff on timber pile at boat dock
					(Sheet 5 of 8)

Table B1 (Continued)					
Waterway	**Map Key**	**Location**	**Lat/Long**	**MLT Ft Below NGVD**	**Comments**
Chart F (Includes NOAA Charts 11316, 11317, and 11319) (Continued)					
GIWW – Colorado River	F11	West side of the east Colorado River lock	28° 40' 58.1" 95° 58' 27.5"	1.43	Staff on steel / timber barge fender
GIWW – Colorado River	F12	West side of the west Colorado River lock	28° 40' 37.64" 95° 59' 02.84"	1.43	Staff on board pounded into channel bottom approx. 5 ft from south bank
GIWW	F13	3,000 ft west of mile marker 445	28° 39' 31.40" 96° 02' 22.46"	N/A	Staff on board pounded into channel bottom approx. 20 ft from south bank
GIWW	F14	Hollywood Matagorda Ship Terminals	28° 37' 12.0" 96° 08" 02.8"	N/A	Staff on timber dock on north bank
GIWW	F15	Coast Guard day marker 5	28° 36' 38.85" 96° 09' 45.31"	N/A	Staff approx. 40 ft from south bank
GIWW – Matagorda Bay	F16	At Stn 540+000 survey table	28° 34' 54.37" 96° 11' 16.46"	N/A	Just south of Oyster Lake
GIWW – Matagorda Bay	N/A	Possibly another staff west of F16	—	N/A	(Staff not visited during survey)
Colorado River	F17	Turning basin	28° 51' 46.45" 96° 11' 16.46"	N/A	Staff on timber pile at ship dock
Colorado River	F18	Approx. 5 mi. south of turning basin	—	N/A	(Staff not visited during survey)
Channel to Red Bluff	F19	Staff at boat ramp under Hwy 616 bridge	28° 50' 01.45" 96° 34' 37.00"	N/A	Staff on timber bulkhead
Port Lavaca Channel	F20	Lighthouse beach and bird sanctuary park near Hwy 35	28° 38' 23.17" 96° 36' 44.11"	N/A	Staff on timber bulkhead near boat ramp
Port Lavaca Channel	F21	Port Lavaca Harbor at Lynn Bayou	28° 37' 20.85" 96° 37' 24.35"	N/A	Staff on timber pile at concrete shrimp boat dock
Port Lavaca Channel	F22	Channel harbor of refuge at Town of Port Lavaca	28° 35' 46.43" 96° 37' 05.09"	N/A	Staff on timber bulkhead at Farm Land ship dock
Matagorda Ship Channel	F23	Lavaca Bay green beacon 71	28° 36' 55.43" 96° 34' 3.23"	1.00	
Matagorda Ship Channel	F24	Turning basin at Point Comfort	28° 38' 25.61" 96° 33' 48.29"	N/A	Staff on survey table near green beacon 79
Matagorda Ship Channel	F25	Lavaca Bay	28° 35' 39.31" 96° 33' 54.70"	1.00	Staff on damaged survey table at beacon 65
Chart G (Includes NOAA Charts 11313 and 11315)					
GIWW	G1	Red day marker 14	28° 19' 17.73" 96° 39' 40.03"	N/A	Day marker near GIWW / Victoria Barge Canal junction
GIWW	G2	Aransas Refuge	28° 13' 37.5" 96° 47' 42.4"	N/A	Aransas wildlife refuge across waterway from the state ramp
GIWW	G3	Survey table at Sundown Bay	28° 11' 02.3" 96° 51' 01.1"	N/A	At Stn 802+532.8 near green day marker 7
					(Sheet 6 of 8)

Table B1 (Continued)

Waterway	Map Key	Location	Lat/Long	MLT Ft Below NGVD	Comments
Chart G (Includes NOAA Charts 11313 and 11315) (Continued)					
Aransas Bay	G4	Goose Island State Park	28° 07' 43.1" 96° 59' 07.6"	N/A	Staff on timber fishing pier near boat ramp
Aransas Bay	G5	Fulton Harbor public boat ramp	28° 03' 37.4" 97° 01' 59.5"	N/A	Staff near end of damaged timber shrimp boat pier
GIWW	G6	Rockport Harbor inner basin	28° 01' 27.3" 97° 03' 00.9"	N/A	Staff in SW side of harbor on timber bulkhead along boat ramp
Channel to Victoria	G7	Green night marker 11	28° 19' 39.56" 96° 41' 20.99"	N/A	Near Victoria "Y" channel
Channel to Victoria	G8	Intersection with Channel to Seadrift	28° 23' 05.53" 96° 43' 40.63"	N/A	Staff mounted on survey table
Channel to Victoria	G9	At Bloomington railroad bridge	—	N/A	Staff on fender wall
GIWW	G10	At Union Carbide Plant's barge canal	—	N/A	Staff on timber pushboat dock
Channel to Seadrift	G11	Seadrift Bait Company	28° 24' 28.0" 96° 42' 44.0"	N/A	Staff on wooden bulkhead
GIWW	G12	Shoalwater Bay at Charlie's Bait Camp	28° 21' 50.6" 96° 34' 51.6"	N/A	Staff on red day marker 8
GIWW	G13	Shoalwater Bay	28° 20' 37.80" 96° 37' 05.14"	N/A	Staff on red day marker 10
GIWW	G14	Near Grass Island	28° 19' 45.82" 96° 38' 46.19"	N/A	Staff on red day marker 12
Chart H (Includes NOAA Charts 11307 and 11308)					
GIWW	H1	Mooring basin Ingleside	27° 48' 55.4" 97° 12' 12.8"	N/A	South of Ingleside; staff on concrete mooring platform
GIWW - Upper Laguna Madre	H2	Staff on USACE survey table near green beacon 169	27° 23' 05.1" 97° 22' 12.4"	N/A	South of Bird Island launch
GIWW - Upper Laguna Madre	H3	USACE survey table at Stn 78+000	27° 29' 01.04" 97° 19' 12.08"	N/A	North of Bird Island launch
GIWW - Upper Laguna Madre	H4	JFK Causeway	27° 38' 05.60" 97° 14' 22.24"	N/A	Staff on cluster of timber piles near ship fender
Aransas Pass Entrance Channel	H5	Port Aransas inner harbor	27° 50' 25.96" 97° 03' 51.46"	N/A	Staff on timber pile on pier (in boat slip)
GIWW - Aransas Pass	H6	North end of Dale Miller Bridge	27° 53' 47.5" 97° 08' 02.9"	N/A	Staff on timber pile cluster under bridge
Corpus Christi Ship Channel	H7	USACE office	27° 48' 37.5" 97° 23' 39.8"	N/A	Staff (missing at time of survey) on concrete bulkhead
Corpus Christi Ship Channel	H8	Harbor Bridge	27° 48' 43.8" 97° 23' 47.1"	N/A	Staff on concrete bulkhead overlooking harbor on south side of channel
La Quinta Channel	H9	Staff on timber platform	27° 50' 16.7" 97° 13' 50.8"	N/A	Platform marks pipeline crossing
Jewell Fulton Channel	H10	North Shore docks in Ingleside	27° 50' 57.0" 97° 13" 18.5"	N/A	Staff on bulkhead in boat slip
La Quinta Channel	H11	State boat ramp at Ingleside Cove	27° 50' 15.6" 97° 13' 13.8"	N/A	Staff on timber pier adjacent to ramp
Corpus Christi Ship Channel	H12	Turning basin at Tule bridge	27° 49' 09.1" 97° 27' 07.3"	N/A	Staff on steel fender

(Sheet 7 of 8)

Table B1 (Concluded)					
Waterway	Map Key	Location	Lat/Long	MLT Ft Below NGVD	Comments
Chart I (Includes NOAA Chart 11304)					
Port Mansfield Channel	I1	Piling - Nav District Warehouse	26° 33' 25.01" 97° 25' 38.63"	N/A	Piling in front of Navigation District Warehouse
Port Mansfield Channel	I2	Beacon #27 at GIWW and channel junction	** 26° 34' 97° 24'	N/A	Beacon 27 shown on chart, not on 020 table
Port Mansfield Channel	I3	Beacon #21	** 26° 34' 97° 22'	N/A	Just to East of Poil bank Levee
Port Mansfield Channel	I4	Beacon #13	** 26° 34' 97° 19'	N/A	½ way from Gulf through Padre Island
Port Mansfield Channel	I5	Beacon #8	** 26° 34' 97° 16'	N/A	Near Gulf and channel junction
GIWW - Upper Laguna Madre	I6	Survey table at Stn 190+863	27° 12' 56.95" 97° 25' 23.69"	N/A	
GIWW - Upper Laguna Madre	I7	South of Yarborough Pass at Stn 242+500	27° 04' 34.11" 97° 26' 32.23"	N/A	Staff on private pier on timber pile; house address 1114
Chart J (Includes NOAA Charts 11301, 11303)					
Channel to Harlingen	J1	End of turning basin	26° 11' 56.99" 97° 35' 56.93"	N/A	
Channel to Harlingen	J2	Beacon #27	26° 18' 18.87" 97° 31' 30.86"	N/A	
Channel to Harlingen	J3	Beacon #32	26° 17' 04.25" 97° 34' 34.49"	N/A	
Channel to Harlingen	J4	Beacon #25	26° 19' 36.87" 97° 30' 47.68"	N/A	
Channel to Harlingen	J5	Beacon #22	26° 19' 55.48" 97° 27' 57.91"	N/A	
Channel to Harlingen	J6	Beacon #19	26° 19' 27.84" 97° 26' 48.28"	N/A	
Brownsville Channel	J9	Center range table	26° 02' 16.61" 97° 12' 43.19"	N/A	New center line range table south side east corner approx. Station 19+400
Brownsville Channel	J10	Beacon #35	26° 00' 56.61" 97° 15' 28.30"	N/A	
Brownsville Channel	J11	Center range table	25° 58' 28.30" 97° 19' 56.93"	N/A	New center line range table on the south side of the channel approx. Station 64+500
Brownsville Channel	J12	Grain Elevator	25° 57' 21.95" 97° 23' 08.11"	N/A	Feature not shown on chart. 020 table: At Grain Elevator east corner facing the channel
Brownsville Channel	J13	West Docks	** 25° 57' 97° 24'	N/A	End of turning basin west docks, south corner just north of navigation district boat ramp
					(Sheet 8 of 8)

REPORT DOCUMENTATION PAGE

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The U.S. Army Engineer District, Galveston, conducts navigation channel maintenance and operations along the Texas coast from the Sabine River on the north to the Brownsville Ship Channel on the south. The Galveston District has identified a need to have both real-time and recorded water-level data in order to conduct navigation channel maintenance and operation, coastal engineering, and environmental regulatory functions in an economical and accurate way. This report identifies general and specific needs for water-level information, and gives recommendations for obtaining such information. Communications alternatives for supplying real-time, voice-reported, and archived data to the Galveston District are discussed.

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